LIBRARIES SMITHSONIAN INSTITUTION

SMITHSONIAN INSTITUTION LIBRARIES

AERONAUTICS

TWELFTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1926

INCLUDING TECHNICAL REPORTS
Nos. 233 to 256

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1927

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
$1.50 PER COPY (PAPER COVERS)

RU 1 24125.

LETTER OF SUBMITTAL

To the Congress of the United States:

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I submit herewith the twelfth annual report of the committee for the fiscal year ended June 30, 1926.

Attention is invited to Part V of the committee's report presenting a summary of the present status of aviation with special reference to technical development and to the aeronautical situation as affected by the constructive legislation enacted at the last session of Congress. Although it will take time to accomplish results under the air commerce act and the approved five-year aircraft-building programs of the Army and Navy, it is gratifying to note the committee's opinion that America leads the world in the private ownership and operation of aircraft, is keeping pace with other nations in the technical development of aircraft for military purposes, and has the technical knowledge necessary at least to equal the commercial developments abroad.

I concur in the committee's opinion that the development of commercial aviation on a sound business basis depends primarily upon the solution of the basic problems of reduction in cost and increase in safety, which are, in turn, in the last analysis largely dependent upon the continuous prosecution of scientific research on the fundamental problems of flight. I believe that the American aviation program is sound in principle and when carried into effect will go far toward making America first in the development of aircraft for military and civil purposes.

Calvin Coolidge.

The White House,
December 9, 1926.

LETTER OF TRANSMITTAL

National Advisory Committee for Aeronautics,
Washington, D. C., November 20, 1926.

Mr. President:

In compliance with the provisions of the act of Congress approved March 3, 1915 (Public, No. 271, 63d Cong.), I have the honor to transmit herewith the Twelfth Annual Report of the National Advisory Committee for Aeronautics for the fiscal year ended June 30, 1926.

Scientific study of the fundamental problems of flight has been continued, and the progress made has been reflected in a steady improvement in performance and reliability of aircraft for all purposes.

The recent enactment by Congress of constructive aeronautical legislation should promote the orderly development of military and naval aviation on a sound basis and should stabilize and encourage the aircraft industry and stimulate commercial aviation.

The present state of development is outlined in Part V of the committee's report. In this part the committee shows the relation of research to national defense and to aeronautical progress in general, and focuses attention on the basic problems of reduction in cost and increase in safety, on which substantial progress must be made in order that the American people may receive the benefits of the full possibilities of aviation.

The report concludes with a statement of the bright outlook for the future, and emphasizes the need for the continuous prosecution of scientific research as the most fundamental activity of the Government in connection with the development of aeronautics.

Respectfully submitted.

Charles D. Walcott,
Chairman.

The President,
The White House,
Washington, D. C.

CONTENTS

Page
Letter of submittal — III
Letter of transmittal — V
Twelfth annual report — 1

PART I. ORGANIZATION

Functions of the committee — 2
Organization of the committee — 2
Meetings of the entire committee — 3
The executive committee — 4
Subcommittees — 4
Committee on governmental relations — 5
Committee on publications and intelligence — 5
Committee on personnel, buildings, and equipment — 5
Quarters for committee — 5
The Langley Memorial Aeronautical Laboratory — 6
The Office of Aeronautical Intelligence — 6
Financial report — 7

PART II. GENERAL ACTIVITIES

Consideration of aeronautic inventions — 8
The air commerce act — 9
Conference with aircraft industry — 12
The Daniel Guggenheim Fund for the Promotion of Aeronautics — 12
Cooperation of Army and Navy — 13
Investigations undertaken for the Army and the Navy — 13
Use of nongovernmental agencies — 14
Cooperation with British Aeronautical Research Committee — 14
Standardization of wind-tunnel results — 15
Standardization of aeronautical symbols and abbreviations — 15
Exhibit at National Sesquicentennial Exposition — 16

PART III. REPORTS OF TECHNICAL COMMITTEES

Report of committee on aerodynamics — 17
Report of committee on power plants for aircraft — 28
Report of committee on materials for aircraft — 36

PART IV. TECHNICAL PUBLICATIONS OF THE COMMITTEE

Summaries of technical reports — 45
List of technical notes issued during the past year — 52
List of technical memorandums issued during the past year — 53
List of aircraft circulars issued during the past year — 55
Bibliography of aeronautics — 56

PART V. THE PRESENT STATUS OF AVIATION

The present state of technical development — 57
Aeronautical legislation and governmental organization — 63
Commercial aviation — 66
Aeronautical research in the United States — 66
Summary — 68
Conclusion — 69

TECHNICAL REPORTS

Page

No. 233. "The Aerodynamic Characteristics of Seven Frequently Used Wing Sections at Full Reynolds Number," by Max M. Munk and Elton W. Miller ---- 71

No. 234. "Three Methods of Calculating Range and Endurance of Airplanes," by Walter S. Diehl ---- 87

No. 235. "Interaction Between Air Propellers and Airplane Structures," by W. F. Durand ---- 105

No. 236. "Tests on Airplane Fuselages, Floats, and Hulls," by Walter S. Diehl ---- 129

No. 237. "Tests on Thirteen Navy Type Model Propellers," by W. F. Durand ---- 151

No. 238. "The Effect of Flight Path Inclination on Airplane Velocity," by Walter S. Diehl ---- 167

No. 239. "Power Output and Air Requirements of a Two-Stroke Cycle Engine for Aeronautical Use," by C. R. Paton and Carlton Kemper ---- 179

No. 240. "Nomenclature for Aeronautics," by National Advisory Committee for Aeronautics ---- 191

No. 241. "Electrical Characteristics of Spark Generators for Automotive Ignition," by R. B. Brode, D. W. Randolph, and F. B. Silsbee ---- 267

No. 242. "Characteristics of a Twin-Float Seaplane During Take-Off," by John W. Crowley, jr., and K. M. Ronan ---- 297

No. 243. "A Preliminary Study of Fuel Injection and Compression Ignition as Applied to an Aircraft Engine Cylinder," by Arthur W. Gardiner ---- 311

No. 244. "Aerodynamic Characteristics of Airfoils–IV," by National Advisory Committee for Aeronautics ---- 327

No. 245. "Meteorological Conditions Along Airways," by W. R. Gregg ---- 369

No. 246. "Tables for Calibrating Altimeters and Computing Altitudes Based on the Standard Atmosphere," by W. G. Brombacher ---- 385

No. 247. "Pressure of Air on Coming to Rest from Various Speeds," by A. F. Zahm ---- 409

No. 248. "The Corrosion of Magnesium and of the Magnesium Aluminum Alloys Containing Manganese," by J. A. Boyer ---- 417

No. 249. "A Comparison of the Take-Off and Landing Characteristics of a Number of Service Airplanes," by Thomas Carroll ---- 455

No. 250. "Description of the N. A. C. A. Universal Test Engine and Some Test Results," by Marsden Ware ---- 467

No. 251. "Approximations for Column Effect in Airplane Wing Spars," by Edward P. Warner and Mac Short ---- 483

No. 252. "The Direct Measurement of Engine Power on an Airplane in Flight with a Hub Type Dynamometer," by W. D. Gove and M. W. Green ---- 503

No. 253. "Flow and Drag Formulas for Simple Quadrics," by A. F. Zahm ---- 515

No. 254. "Distribution of Pressure over Model of the Upper Wing and Aileron of a Fokker D–VII Airplane," by A. J. Fairbanks ---- 539

No. 255. "Pressure Distribution Over Airfoils at High Speeds," by L. J. Briggs and H. L. Dryden ---- 553

No. 256. "The Air Forces on a Systematic Series of Biplane and Triplane Cellule Models," by Max M. Munk ---- 595

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

3341 NAVY BUILDING, WASHINGTON, D. C.

Charles D. Walcott, Sc. D., *Chairman,*
 Secretary, Smithsonian Institution, Washington, D. C.
David W. Taylor, D. Eng., *Secretary,*
 Washington, D. C.
Joseph S. Ames, Ph.D., *Chairman Executive Committee,*
 Director Physical Laboratory, Johns Hopkins University, Baltimore, Md.
George K. Burgess, Sc. D.,
 Director, Bureau of Standards, Washington, D. C.
John F. Curry, Major, United States Army,
 Matériel Division, Air Corps, McCook Field, Dayton, Ohio.
William F. Durand, Ph. D.,
 Professor of Mechanical Engineering, Stanford University, California.
Emory S. Land, Captain, United States Navy,
 Assistant Chief, Bureau of Aeronautics, Navy Department, Washington, D. C.
Charles F. Marvin, M. E.,
 Chief, United States Weather Bureau, Washington, D. C.
William A. Moffett, Rear Admiral, United States Navy,
 Chief, Bureau of Aeronautics, Navy Department, Washington, D. C.
Mason M. Patrick, Major General, United States Army,
 Chief of the Air Corps, War Department, Washington, D. C.
S. W. Stratton, Sc. D.,
 President, Massachusetts Institute of Technology, Cambridge, Mass.
Orville Wright, B. S.,
 Dayton, Ohio.

EXECUTIVE COMMITTEE

Joseph S. Ames, *Chairman.*
David W. Taylor, *Secretary.*

George K. Burgess.
John F. Curry.
Emory S. Land.
Charles F. Marvin.
William A. Moffett.
Mason M. Patrick.
S. W. Stratton.
Charles D. Walcott.
Orville Wright.

George W. Lewis, *Director of Aeronautical Research.*
John F. Victory, *Assistant Secretary.*

TWELFTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 17, 1926.*

To the Congress:

In accordance with the act of Congress approved March 3, 1915, establishing the National Advisory Committee for Aeronautics, the committee submits herewith its twelfth annual report for the fiscal year 1926. Final approval of the committee was given to this report on November 9, 1926. In this report the committee has described its organization; its general activities during the past year; the progress made in the scientific study, under the cognizance of the various technical subcommittees, of the fundamental problems of aeronautics; the coordination of research work in general; the creation by law of the Aeronautical Patents and Design Board and the relations of the committee with that board in connection with the consideration of aeronautical inventions; the principles embodied in the air commerce act for the encouragement of commercial aviation and the committee's part in connection with the formulation thereof; and the collection, analysis and dissemination of scientific and technical data. This report also contains brief descriptions of the technical reports, and references to the technical notes, technical memorandums, and aircraft circulars issued by the committee during the past year.

A statement of expenditures for the fiscal year ended June 30, 1926, is also contained in the report.

In Part V of his report, the committee presents an outline of "The Present Status of Aviation," including references to the present state of technical development; aeronautical research in the United States and its relation to national defense; the general problem of aeronautical organization, with a summary of the legislative situation; the status of commercial aviation; references to the Air Mail Service, the aircraft industry, and to the relation of the work of the committee to aeronautical progress.

PART I

ORGANIZATION

FUNCTIONS OF THE COMMITTEE

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915. The organic act charges the committee with the supervision and direction of the scientific study of the problems of flight with a view to their practical solution, the determination of problems which should be experimentally attacked, and their investigation and application to practical questions of aeronautics. The act also authorized the committee to direct and conduct research and experimentation in aeronautics in such laboratory or laboratories, in whole or in part, as may be placed under its direction.

Supplementing the prescribed duties of the committee under its organic act, its broad general functions may be stated as follows:

First. Under the law the committee holds itself at the service of any department or agency of the Government interested in aeronautics, for the furnishing of information or assistance in regard to scientific or technical matters relating to aeronautics, and in particular for the investigation and study of fundamental problems submitted by the War and Navy Departments with a view to their practical solution.

Second. The committee may also exercise its functions for any individual, firm, association, or corporation within the United States, provided that such individual, firm, association, or corporation defray the actual cost involved.

Third. The committee institutes research, investigation, and study of problems which, in the judgment of its members or of the members of its various subcommittees, are needful and timely for the advance of the science and art of aeronautics in its various branches.

Fourth. The committee keeps itself advised of the progress made in research and experimental work in aeronautics in all parts of the world, particularly in England, France, Italy, Germany, and Canada.

Fifth. The information thus gathered is brought to the attention of the various subcommittees for consideration in connection with the preparation of programs for research and experimental work in this country. This information is also made available promptly to the military and naval air services and other branches of the Government, and such as is not confidential is immediately released to university laboratories and aircraft manufacturers interested in the study of specific problems, and also to the public.

Sixth. The committee holds itself at the service of the President, the Congress, and the executive departments of the Government for the consideration of special problems which may be referred to it.

During the past year the Congress made the first legislative change in the functions of the committee. In the act approved July 2, 1926, an Aeronautical Patents and Design Board was created, consisting of Assistant Secretaries of War, Navy, and Commerce. Section 10(r) of that act (Public, No. 446, 69th Cong.) provided that "upon the recommendation of the National Advisory Committee for Aeronautics" the Patents and Design Board shall determine questions as to the use and value to the Government of aeronautical inventions submitted to any branch of the Government.

ORGANIZATION OF THE COMMITTEE

The committee has 12 members, appointed by the President. The law provides that the personnel of the committee shall consist of two members from the War Department, from the office in charge of military aeronautics; two members from the Navy Department, from the office in charge of naval aeronautics; a representative each of the Smithsonian Institution, the United States Weather Bureau, and the United States Bureau of Standards; and not more than five additional persons acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences. The law further provides that all members as such shall serve without compensation.

No change has occurred during the past year in the membership of the committee.

During the last session of Congress a bill was passed by the Senate (S. 4529) providing for an increase in the membership of the National Advisory Committee for Aeronautics from 12 to 15 to include the new Assistant Secretaries of War, Navy, and Commerce. A similar bill was introduced in the House of Representatives and was favorably reported by the committee to which it was referred, but was not reached for consideration prior to the adjournment of Congress.

The entire committee meets twice a year, the annual meeting being held in October and the semiannual meeting in April. The present report includes the activities of the committee between the annual meeting held on October 22, 1925, and that held on October 21, 1926.

The organization of the committee at the close of the past year was as follows:

Charles D. Walcott, Sc. D., chairman.
David W. Taylor, D. Eng., secretary.
Joseph S. Ames, Ph. D.
George K. Burgess, Sc. D.
Maj. John F. Curry, United States Army.
William F. Durand, Ph. D.
Capt. Emory S. Land, United States Navy.
Charles F. Marvin, M. E.
Rear Admiral William A. Moffett, United States Navy.
Maj. Gen. Mason M. Patrick, United States Army.
S. W. Stratton, Sc. D.
Orville Wright, B. S.

MEETINGS OF THE ENTIRE COMMITTEE

The semiannual meeting of the entire committee was held at the Langley Memorial Aeronautical Laboratory, Langley Field, Hampton, Va., on April 22, 1926, and the annual meeting in Washington on October 21, 1926. At these meetings the general progress in aeronautical research was reviewed and the problems which should be experimentally attacked were discussed. Administrative reports were submitted by the Secretary and by the Director of the Office of Aeronautical Intelligence. Doctor Ames, chairman of the executive committee, made complete reports of the research work being conducted by the committee at the Langley Memorial Laboratory and reported briefly on the general activities of the committee.

In connection with the semiannual meeting at Langley Field on April 22, the committee made an inspection of the facilities and activities of its laboratory, the various investigations under way being explained in detail by members of the laboratory staff. On that occasion also the members of the committee were conducted by the commanding officer of Langley Field on a tour of inspection of the Army's flying facilities and airship hangar, where they saw the nonrigid airship *TC-4* and the recently developed tank car especially designed for the transportation of helium.

At the annual meeting in Washington on October 21, a motion-picture film was exhibited showing some of the tests being conducted at the Langley Memorial Aeronautical Laboratory on the problem of autorotation, or the flat spin. At this meeting also the committee had as its guests Hon. Edward P. Warner, Assistant Secretary of the Navy, and Hon. William P MacCracken, jr., Assistant Secretary of Commerce. Assistant Secretary of War Davison, who had been invited as a guest, and General Patrick were absent from the city. Brig. Gen. William E. Gillmore, new chief of the matériel division of the Army Air Corps, was present on invitation as a representative of General Patrick.

The election of officers was the concluding feature of the annual meeting. The present officers of the committee were elected for another year, as follows: Chairman, Dr. Charles D. Walcott, secretary; Dr. David W. Taylor; chairman, executive committee, Dr. Joseph S. Ames.

THE EXECUTIVE COMMITTEE

For carrying out the work of the Advisory Committee the regulations provide for the election annually of an executive committee, to consist of seven members, and to include in addition any member of the Advisory Committee not otherwise a member of the executive committee but resident in or near Washington and giving his time wholly or chiefly to the special work of the committee. The present organization of the executive committee is as follows:

Joseph S. Ames, Ph. D., chairman.
David W. Taylor, D. Eng., secretary.
George K. Burgess, Sc. D.
Maj. John F. Curry, United States Army.
Capt. Emory S. Land, United States Navy.
Charles F. Marvin, M. E.
Rear Admiral William A. Moffett, United States Navy.
Maj. Gen. Mason M. Patrick, United States Army.
S. W. Stratton, Sc. D.
Charles D. Walcott, Sc. D.
Orville Wright, B. S.

The executive committee, in accordance with the general instructions of the Advisory Committee, exercises the functions prescribed by law for the whole committee, administers the affairs of the committee, and exercises general supervision over all its activities.

During the past year the executive committee, on invitation of General Patrick and Major Curry, held one of its regular meetings at McCook Field, Dayton, Ohio, in connection with which the members inspected the facilities and activities of the Engineering Division of the Army Air Corps. At its last meeting the executive committee accepted an invitation from Admiral Moffett for the members to visit the naval aircraft factory, at the Philadelphia Navy Yard, and become directly acquainted with the work in progress there.

The executive committee has organized the necessary clerical and technical staffs for handling the work of the committee proper. General responsibility for the execution of the research program in aeronautics approved by the executive committee is vested in the director of aeronautical research, Mr. George W. Lewis. In the subdivision of general duties he has immediate charge of the scientific and technical work of the committee, being directly responsible to the chairman of the executive committee, Dr. Joseph S. Ames. The assistant secretary, Mr. John F. Victory, has charge of administration and personnel matters, property, and disbursements, under the direct control of the secretary of the committee, Dr. David W. Taylor.

SUBCOMMITTEES

The executive committee has organized six standing subcommittees, divided into two classes, administrative and technical, as follows:

ADMINISTRATIVE	TECHNICAL
Governmental relations.	Aerodynamics.
Publications and intelligence.	Power plants for aircraft.
Personnel, buildings, and equipment.	Materials for aircraft.

The organization and work of the technical subcommittees are covered in the reports of those committees appearing in another part of this report. A statement of the organization and functions of the administrative subcommittees follows:

COMMITTEE ON GOVERNMENTAL RELATIONS

FUNCTIONS

1. Relations of the committee with executive departments and other branches of the Government.
2. Governmental relations with civil agencies.

ORGANIZATION

Dr. Charles D. Walcott, chairman.
Dr. David W. Taylor.
John F. Victory, secretary.

COMMITTEE ON PUBLICATIONS AND INTELLIGENCE

FUNCTIONS

1. The collection, classification, and diffusion of technical knowledge on the subject of aeronautics, including the results of research and experimental work done in all parts of the world.
2. The encouragement of the study of the subject of aeronautics in institutions of learning.
3. Supervision of the Office of Aeronautical Intelligence.
4. Supervision of the committee's foreign office in Paris.
5. The collection and preparation for publication of the technical reports, technical notes, technical memorandums, and aircraft circulars of the committee.

ORGANIZATION

Dr. Joseph S. Ames, chairman.
Prof. Charles F. Marvin, vice chairman.
Miss M. M. Muller, secretary.

COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT

FUNCTIONS

1. To handle all matters relating to personnel, including the employment, promotion, discharge, and duties of all employees.
2. To consider questions referred to it and make recommendations regarding the initiation of projects concerning the erection or alteration of laboratories and offices.
3. To meet from time to time on the call of the chairman, and report its actions and recommendations to the executive committee.
4. To supervise such construction and equipment work as may be authorized by the executive committee.

ORGANIZATION

Dr. Joseph S. Ames, chairman.
Dr. David W. Taylor, vice chairman.
Prof. Charles F. Marvin.
John F. Victory, secretary.

QUARTERS FOR COMMITTEE

The headquarters of the National Advisory Committee for Aeronautics are located in the Navy Building, Seventeenth and B Streets NW., Washington, D. C., in close proximity to the Army and Navy services. The administrative office is also the headquarters of the various subcommittees and of the Office of Aeronautical Intelligence.

Field stations of the committee are the Langley Memorial Aeronautical Laboratory, at Langley Field, Hampton, Va., and the office of the technical assistant in Europe, located in Paris.

The scientific investigations authorized by the committee are not all conducted at the Langley Memorial Aeronautical Laboratory, but the facilities of other governmental laboratories and shops are utilized, as well as the laboratories connected with institutions of learning whose cooperation in the scientific study of specific problems in aeronautics has been secured.

THE LANGLEY MEMORIAL AERONAUTICAL LABORATORY

The greater part of the research work of the committee is conducted at the Langley Memorial Aeronautical Laboratory, which is located at Langley Field, Va., on a plot of ground set aside by the War Department for the use of the committee when Langley Field was originally laid out. Langley Field is one of the most important and best equipped stations of the Army Air Corps, occupying about 1,650 acres and having hangar and shop facilities for the accommodation of four bombing squadrons, a service squadron, a school squadron, and an airship squadron.

The laboratory is organized with four subdivisions, as follows: Aerodynamics division, power plants division, technical service division, and property and clerical division. The administration of the laboratory is under the immediate direction of an engineer in charge, Mr. Henry J. E. Reid, subject to the general supervision of the officers of the committee.

The laboratory consists of seven buildings: A research laboratory building, containing the administrative offices, the headquarters of the aerodynamics and power plants divisions, the technical library, the photographic laboratory, and a lunch room; two aerodynamical laboratories, one containing a wind tunnel of the open type and the other a variable-density wind tunnel, each unit being complete in itself; two engine dynomometer laboratories of a semipermanent type, both equipped to carry on investigations in connection with power plants for aircraft; an airplane hangar equipped with a repair shop, dope room, and facilities for taking care of 16 or 18 airplanes used in flight research; and a service building, containing an instrument laboratory, drafting room, machine and woodworking shops, and storeroom.

On June 25, 1925, the committee authorized the construction of propeller research equipment large enough to investigate full-sized propellers. It is expected that the propeller research equipment will be completed and in operation before the end of this fiscal year. The test chamber will be of sufficient size to accommodate the fuselage of an airplane, on which the propeller will be mounted and operated by the airplane engine. The throat of the test chamber will be 20 feet in diameter and the air speed will be approximately 100 miles an hour.

Recognition by the Government of the necessity of satisfying the increasing demand for new and accurate knowledge on the fundamental problems of flight has made possible the development of the Langley Memorial Aeronautical Laboratory as an efficient research organization numbering 126 employees at the close of the fiscal year 1926.

THE OFFICE OF AERONAUTICAL INTELLIGENCE

The Office of Aeronautical Intelligence was established in the early part of 1918 as an integral branch of the committee's activities. Its functions are the collection, classification, and diffusion of technical knowledge on the subject of aeronautics to the military and naval air organizations and civil agencies interested, including especially the results of research and experimental work conducted in all parts of the world. It is the officially designated Government depository for scientific and technical reports and data on aeronautics.

Promptly upon receipt, all reports are analyzed and classified, and brought to the special attention of the subcommittees having cognizance, and to the attention of other interested parties through the medium of public and confidential bulletins. Reports are duplicated where practicable, and distributed upon request. Confidential bulletins and reports are not circulated outside of Governmental channels.

To handle efficiently the work of securing and exchanging reports in foreign countries, the committee maintains a technical assistant in Europe, with headquarters in Paris. It is his duty to visit personally the governmental and private laboratories, centers of aeronautical information, and private individuals in England, France, Italy, Germany, and other European countries, and endeavor to secure for America not only printed matter which would in the ordinary course of events become available in this country, but more especially to secure advance information as to work in progress, and any technical data not prepared in printed form, and which would otherwise not reach this country. Mr. John Jay Ide, or New York, is the present incumbent.

The records of the office show that during the past year copies of technical reports and papers were distributed as follows:

Committee and subcommittee members	1, 010
Langley Memorial Aeronautical Laboratory	2, 074
Paris office of the committee	3, 581
Army Air Corps	2, 988
Naval air organization, including Marine Corps	3, 015
Manufacturers	4, 637
Educational institutions	5, 259
Bureau of Standards	444
Miscellaneous requests	16, 199
Total distribution	39, 207

The above figures include the distribution of 16,725 technical reports, 6,624 technical notes, 7,729 technical memorandums, and 984 aircraft circulars of the National Advisory Committee for Aeronautics. Five thousand six hundred and twenty-nine written requests for reports were received during the year in addition to innumerable telephone and personal requests, and 21,029 reports were forwarded upon request.

FINANCIAL REPORT

The appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1926, as carried in the independent offices appropriation act approved April 22, 1926, was $522,000, under which the committee reports expenditures and obligations during the year amounting to $516,709.27, itemized as follows:

Salaries (including engineering staff)	$192, 884. 43
Wages	109, 763. 96
Supplies and materials	22, 562. 11
Communication service	1, 059. 52
Travel	12, 826. 75
Transportation of things	4, 962. 26
Furnishing of electricity	10, 968. 60
Rent	634. 78
Repairs and alterations	3, 097. 29
Special investigations	33, 450. 00
Equipment	84, 507. 07
Laboratory Building	39, 992. 50
Expenditures	516, 709. 27
Reserve, "One Per Cent Club"	5, 245. 00
Unexpended balance	45. 73
Total	522, 000. 00

In addition to the above, the committee had a separate appropriation of $12,000 for printing and binding, of which $11,518.19 was expended.

PART II

GENERAL ACTIVITIES

CONSIDERATION OF AERONAUTIC INVENTIONS

The President's Aircraft Board, known as the Morrow Board, in Section III (7) of its report submitted to the President November 30, 1925, recommended that "the functions of the National Advisory Committee for Aeronautics should be extended to cover the field of advice to inventors regarding aeronautic inventions." The executive committee at its meeting on February 5, 1926, went on record as being willing to assume definitely the duty of rendering such further assistance in this respect as the Congress may determine. This was followed on February 17, 1926, by a letter from The Adjutant General of the Army stating that all aeronautic inventions received by the War Department would be referred to the committee with the understanding that "these inventions will be investigated and such action will be taken as appears advisable in each case." By a prior agreement with the Navy Department dated April 12, 1921, the Navy had been referring to the committee "all inventions on aeronautics of a general character and not of a specific value to the Navy nor in reply to a request for designs."

The committee had first begun the consideration of aeronautic inventions during the war period at the request of War and Navy representatives on the committee. After the war the committee continued to receive inventions and to advise inventors and the military services upon all inventions submitted by individuals direct or through other governmental agencies. The difficulties with this method were:

1. That there was no agency with power on the part of the Government to reimburse an inventor for a valuable design.

2. The committee could only advise an inventor, and there was no governmental agency authorized to render a final decision on the merits of an invention.

The Congress met this situation by the creation of a patents and design board composed of Assistant Secretaries of War, Navy, and of Commerce. This legislation was contained in the Army Air Corps act (Public, No. 446, 69th Cong.), section 10(r) of which reads as follows:

> A board to be known as the Patents and Design Board is hereby created, the three members of which shall be an Assistant Secretary of War, an Assistant Secretary of the Navy, and an Assistant Secretary of Commerce. To this board any individual, firm, or corporation may submit a design for aircraft, aircraft parts, or aeronautical accessories, and whether patented or unpatentable, the said board upon the recommendation of the National Advisory Committee for Aeronautics shall determine whether the use of such designs by the Government is desirable or necessary, and evaluate the designs so submitted and fix the worth to the United States of said design, not to exceed $75,000. The said designer, individual, firm, or corporation, may then be offered the sum fixed by the board for the ownership or a nonexclusive right of the United States to the use of the design in aircraft, aircraft parts, or aeronautical accessories and upon the acceptance thereof shall execute complete assignment or nonexclusive license to the United States: *Provided,* That no sum in excess of $75,000 shall be paid for any one design.

The Patents and Design Board held its first meeting on October 12, 1926, and was composed of the following:

Hon. F. Trubee Davison, Assistant Secretary of War for Aeronautics;
Hon. Edward P. Warner, Assistant Secretary of the Navy for Aeronautics;
Hon. William P. MacCracken, jr., Assistant Secretary of Commerce for Aeronautics.

Mr. Davison as representative of the ranking department presided, and Mr. Warner acted as recorder.

The Patents and Design Board decided at the outset that it would be a board of record and it was agreed in the interests of economy that the National Advisory Committee for Aeronautics would maintain the records of the board separate and distinct from its own records.

The board adopted an outline of procedure which provides among other things that all projects must be submitted in full and in writing; that they would be referred in the first instance to the National Advisory Committee for Aeronautics for consideration, preparation of an abstract, and recommendation to the board; that final action on each project so considered would be taken at meetings of the board to be held periodically; that personal interviews with inventors would not be granted by the board except after full consideration of the invention, provided that in cases offering prospect of favorable action, the inventor should be invited to appear before the board for its further information.

In the meantime, the National Advisory Committee for Aeronautics had appointed a special subcommittee to determine its procedure in discharging the additional duties devolving upon it under the act that created the Patents and Design Board. This subcommittee consisted of Dr. D. W. Taylor, chairman, Rear Admiral William A. Moffett, United States Navy, and Maj. Gen. Mason M. Patrick, United States Army.

On October 18, 1926, this subcommittee made a report recommending that the outline of procedure adopted by the Patents and Design Board in so far as it relates to the procedure of the committee, be approved as a governing policy of the committee. The subcommittee's report contained the following further recommendations which were made "in harmony with the above procedure or with the known views of the members of the board":

> (1) That the National Advisory Committee for Aeronautics consider and report to the board on all aeronautical inventions received direct or referred to the committee by the board or by any other governmental agency.
>
> (2) That in the consideration of an invention the committee will conduct with the inventor such direct correspondence as may be necessary to disclose clearly his idea and will then submit to the Board on Patents and Design the papers in the case together with an abstract of the invention and the committee's recommendation.
>
> (3) That a technical committee on aeronautical patents and design be not organized at this time but that the Director of Aeronautical Research be authorized to act for the National Advisory Committee for Aeronautics in respect to the committee's functions as outlined in one and two above and in connection therewith to call upon any subcommittee or member thereof for advice or assistance, provided that in his discretion important or doubtful cases may be submitted to the executive committee for determination of the committee's recommendation to be submitted to the Board on Patents and Design.
>
> (4) That in the interests of efficiency and economy the committee offer the use of its conference room for meetings of the Board on Patents and Design and agree so long as may be deemed necessary to provide the necessary personnel and facilities for the maintenance of the board's records separate and distinct from the records of the committee.

The report of the subcommittee was approved by the executive committee of the National Advisory Committee for Aeronautics on October 21, and became a governing policy of the committee. A satisfactory beginning has been made by the Patents and Design Board and the National Advisory Committee for Aeronautics acting in cooperation in the consideration of aeronautic inventions in full compliance with the spirit of the new law referred to.

THE AIR COMMERCE ACT

The year 1926 will be memorable in aeronautics as marking the year in which Congress enacted the air commerce act. (Public—No. 254—69th Cong.—S. 41.) This act provides the legislative cornerstone for the development of commercial aviation in America. It establishes certain fundamental principles to govern the relation of the Federal Government to the whole problem of aiding the development of commercial aviation in America on a sound basis. The act asserts the doctrine of Federal sovereignty in the air over the lands and waters of the United States to the exclusion of foreign nations. It asserts under the commerce clause of the Constitution the right of the Federal Government to regulate interstate air commerce. It authorizes the designation of airways by the Federal Government and compels adherence to a single set of Federal flying rules on the part of all who use such airways, regardless of whether they are engaged in interstate or intrastate air commerce or private flying. It authorizes Federal lighting systems along airways and the Federal establishment and maintenance of emergency landing fields. It authorizes the transfer of the postal airways, including emeregncy landing fields, to the jurisdiction of the Department of Commerce and the transfer of the postal air ports or terminal facilities to the jurisdiction of the municipalities concerned under arrangements subject to approval by the President. It contemplates the establishment and maintenance of air ports by the municipalities or by private industries. It provides for the compulsory registration of aircraft engaged in interstate commerce and for the optional registration of other aircraft. It provides for the periodic examination and rating of airmen serving in connection with registered aircraft. It provides for the emergency use of existing governmental facilities, extends the application of existing laws to foreign air traffic, and, in short, imposes upon the administrative officer concerned—the Secretary of Commerce—the duty of fostering the development of air commerce in the United States.

Although there had been an almost universal desire among all aeronautical elements in this country for Federal legislation to regulate and encourage commercial aviation, there were conflicting schools of thought on the principles to be followed and the methods to be employed. After the bill had passed both the Senate and House of Representatives and while it was in conference there were differences as to fundamental principles which threatened for a time the enactment of the legislation into law. In this situation Senator Bingham, of Connecticut, the sponsor of the legislation in the Senate and one of the Senate conferees, called upon the National Advisory Committee for Aeronautics on April 15, 1926, for "a full report embodying such constructive criticisms and recommendations as your committee may deem advisable and necessary." At the semiannual meeting of the entire committee, held at Langley Field, Va., on April 22, a special subcommittee on the encouragement and regulation of aircraft in commerce was organized in response to Senator Bingham's letter, as follows:

William F. Durand, chairman.
Joseph S. Ames, Johns Hopkins University.
George K. Burgess, Director Bureau of Standards.
Maj. John F. Curry, United States Army, Chief Engineering Division, McCook Field.
Capt. Emory S. Land, United States Navy, Bureau of Aeronautics.
Rear Admiral William A. Moffett, United States Navy, Chief, Bureau of Aeronautics, Navy.
Maj. Gen. Mason M. Patrick, United States Army, Chief of Air Service, War Department.
S. W. Stratton, president Massachusetts Institute of Technology.
David W. Taylor, secretary National Advisory Committee for Aeronautics.
Orville Wright.

This special subcommittee considered the air bill carefully and submitted a unanimous report, which was approved by the National Advisory Committee for Aeronautics and transmitted to Senator Bingham on April 23. In its report the subcommittee enumerated a number of changes in important details deemed advisable, but focused its attention primarily on two principles involved which it characterized as "fundamentally unsound and prejudicial alike to the best interests of aviation and to the Government." These were the policies at that time contained in the bill providing for the Federal establishment and operation of airports and for the extension of Federal control to include all air navigation.

FEDERAL ESTABLISHMENT AND OPERATION OF AIRPORTS

After citing specific provisions of the bill authorizing the Federal establishment and operation of airports, the subcommittee in its report commented on this principle as follows:

> The policy of the Federal Government regarding airports and the encouragement of air navigation should be analogous to its policy regarding seaports and the encouragement of water navigation. In the latter field the Government makes charts, establishes and maintains ligthhouses, dredges channels, furnishes weather forecasts and storm warnings, and provides for inspection and licensing, but leaves to municipal authorities the control of port facilities. In aid of air navigation the Federal Government should chart airways, establish markers, including lights for night flying, establish and maintain emergency landing fields, furnish weather-report service, and provide for inspection and licensing, but leave to municipal authorities the control of airports.

Although it is not clearly stated in any one place, the bill does authorize the Secretary of Commerce to purchase, establish, maintain, and operate airports. If this measure should become a law in its present form, the effect would be to destroy the initiative of municipalities in providing their own airports and to bring about demands for large appropriations by Congress for the acquisition by the Secretary of Commerce of land in cities and towns in all parts of the country, and the preparation of such land for use as airports. The financial burden on the Federal Treasury would be so tremendous that it would take a great many years to carry the policy into effect, if, indeed, the responsibility thus assumed would ever be discharged. One result would be certain: Airports would not be established as needed, and the primary object of the bill—the encouragement of commercial aviation—would be defeated. On the other hand, if the municipalities desiring airports are given to understand that they must provide their own airports, the job can be accomplished simultaneously and without delay in all such cities and towns, and the cost involved would fall where it properly belongs.

As to the disposition of the postal airports, after the Post Office Department has placed the air transportation of the mails upon a contract basis and has gone out of the business of operating aircraft, it would be a mistake to transfer these airports to the Secretary of Commerce to be maintained and operated by the Federal Government. This would involve discrimination between the cities that had postal airports and those that had not. It would be the entering wedge for Federal operation of airports. It is considered of great importance as a matter of policy that the Secretary of Commerce should not at any time be engaged in the operation of postal airports, for, if the precedent were to be established, the bad effects might last a long time. The postal airports should be transferred to the municipalities concerned, upon arrangements to be made by the Postmaster General, subject to approval by the President, or if no satisfactory arrangements can be made they should be closed and the properties disposed of as are any other public properties no longer needed by the Federal Government.

The report then recommended specific changes in the bill to carry into effect the views expressed.

FEDERAL CONTROL OF ALL FLYING

Under the subject of Federal control of all flying, the subcommittee reported as follows:

The bill as it passed the Senate provided for Federal control of air navigation used in interstate or foreign commerce. The bill as it passed the House extends Federal control to intrastate commerce and to private flying, interstate and intrastate. This principle involves two major considerations—one of constitutionality, the other of policy. Although it appears to your committee that private flying can not be construed to constitute "commerce" in the legal sense and that its regulation by the Federal Government can not therefore be justified under the commerce clause of the Constitution, nevertheless your committee does not feel competent to do more than sound a note of warning as to the doubtful constitutionality of this feature of the bill, and will confine itself primarily to the matter of policy involved.

Assuming for the sake of argument that the regulation of intrastate air commerce and of all private flying is constitutional, is it advisable? The primary purpose of the whole bill is, or should be, to encourage commercial aviation, and as an incident to that encouragement to provide reasonable and needful regulations. The regulation of private flying is not necessary at this time to encourage the development of commercial aviation, nor is the regulation of intrastate air commerce necessary to the major purpose of the bill—encouragement of commercial aviation. In the judgment of your committee, the wisest policy to pursue at this time is to provide a maximum of encouragement with a minimum of regulation.

Commercial aviation has not been able to exist in European countries without direct subsidies that amount to from 50 to 95 per cent of the cost of the service rendered the public. Commercial aviation, on a sound commercial basis is nonexistent in Europe. Private flying, due largely to strict and unnecessary governmental regulation, is at a very low ebb in European countries. Although authentic statistics are not available, it is the judgment of your committee that there are in America to-day more privately owned and operated aircraft than in all Europe, and that the reason for this condition is that private flying in Europe has suffered from premature regulation as well as from overregulation, whereas private flying in America has had complete freedom of development. We believe that the effect of the bill in its present form on private flying in America will be to drive out of the air a major portion of the privately owned aircraft and private flyers, primarily because of the nuisance and inconvenience of unnecessary regulations. It is therefore recommended that the regulatory provisions of the bill be limited to the regulation of aircraft engaged in interstate or foreign commerce.

The subcommittee then proposed changes in the text deemed necessary to accomplish its recommendation in this respect, and in the conclusion of its report said:

We are strongly in favor of the enactment of legislation to encourage and regulate commercial aviation. We believe that the objections presented to the principle of Federal establishment of airports and to the principle of Federal regulation of private flying at this time and in the manner proposed in this bill are fundamental, and that it would be better that the bill should fail of enactment than that either of these principles should be retained.

In transmitting to Senator Bingham the report of the subcommittee, which was signed by each of the 10 members, Doctor Walcott, chairman of the National Advisory Committee for Aeronautics, concurred and invited particular attention to the concluding recommendation as above. The report of the subcommittee was presented to the conferees on the bill and the changes in principles recommended by the committee were accepted, and along with some other minor changes were incorporated into the conference report which was adopted soon after by the Senate and House of Representatives and the measure was approved by the President and became a law on May 20, 1926.

The act created the position of an additional Assistant Secretary of Commerce specifically to aid in the administration of the Federal air law and in the encouragement of commercial aviation.

Although the air commerce act may not be without fault in some details, it is the opinion of the committee that experience will show that it is sound in principle and that it will prove to be the legislative foundation for the air commerce of the future.

CONFERENCE WITH AIRCRAFT INDUSTRY

Up to the present time the greater part of the productive thought and energy of those interested in the development of aviation has been devoted to the interests of military and naval aviation. In this respect the problems of the manufacturers and of the Government were largely merged and came under regular consideration by the committee through its subcommittees. With the passage of the air commerce act of 1926, an impetus has been given to the growth of commercial aviation, and the committee is of the opinion that a new series of problems peculiar to commercial aviation will confront manufacturers and operators of aircraft.

In accordance with the policy announced in its last annual report, and in order to give the representatives of the industry an opportunity to present some of the new problems arising out of commercial aviation with a view to the incorporation of the same in the committee's research program, the committee held, on May 24, 1926, at the Langley Memorial Aeronautical Laboratory, Langley Field, Va., its first joint conference with representatives of aircraft manufacturers and operators. At this conference the committee was represented by its subcommittee on aerodynamics and members of the laboratory staff, Dr. Joseph S. Ames, chairman of the executive committee and of the subcommittee on aerodynamics, acting as chairman.

At a preliminary meeting held in the morning the history, functions, and work of the committee were briefly outlined, following which the representatives of the industry were shown the facilities of the laboratory and the character of the problems under investigation. In the afternoon the conference proper convened. After a brief statement by the chairman as to the purpose of the meeting, there was general discussion of the problems of commercial aviation, in which the representatives of the industry participated. Among the needs of commercial aviation as pointed out were the development of a small, light airplane for individual use, which would have the ability to take off and land in a much smaller space and which would be safer than present-type airplanes; further information as to the problem of control at low speeds; and greater consideration in airplane design for the comfort and convenience of passengers. One research problem proposed at the conference, the investigation of the M–6 and M–12 airfoils equipped with trailing edge flaps, was promptly incorporated in the committee's research program.

Following the conference an executive session of the committee on aerodynamics was held, while the representatives of the industry were conducted on an inspection of the Army facilities at Langley Field as the guests of the commanding officer and witnessed a special aerial demonstration which had been arranged in their honor.

THE DANIEL GUGGENHEIM FUND FOR THE PROMOTION OF AERONAUTICS

On January 16, 1926, Mr. Daniel Guggenheim announced the foundation of the Daniel Guggenheim Fund for the Promotion of Aeronautics and his intention to place at its disposal the sum of $2,500,000. The fund is administered by a board of directors consisting of 15 members representatives of the highest type of commercial and scientific activities, and the whole fund, including principal and interest, is available for expenditure in the discretion of the board.

According to the statement of the founder, the general purposes to which the new fund will devote itself may be broadly defined as follows:

1. To promote aeronautical education both in institutions of learning and among the general public.
1. To assist in the extension of fundamental aeronautical science.
3. To assist in the development of commercial aircraft and aircraft equipment.
4. To further the application of aircraft in business, industry, and other economic and social activities of the Nation.

Two members of the National Advisory Committee for Aeronautics, Dr. W. F. Durand, past chairman, and Mr. Orville Wright, are members of the board of directors. From the statement of the purposes of the fund and the obviously high character of the members of the board of directors, it may be confidently expected that its activities will be carefully planned to produce a maximum of immediately practical and substantial assistance to aviation in its commercial, industrial, and scientific aspects, while at the same time avoiding duplication with existing agencies, governmental and private.

COOPERATION OF ARMY AND NAVY

Through the personal contact of the heads of the Army and Navy air organizations serving on the main committee and the frequent personal contact on the subcommittees of their chief subordinates who have to do with technical matters in aeronautics, there has been accomplished in fact not only a coordination of aeronautical research, which is the major function of the committee, but also a coordination of experimental engineering activities of the services and an exchange of first-hand information, comment, and suggestions that have had beneficial effects in both services. The needs of each service in the field of aeronautical research are discussed and agreements invariably reached that promote the public interests. The cordial relations that usually follow from frequent personal contact are supplemented by the technical information service of the committee's office of aeronautical intelligence, which makes available the latest scientific data and technical information secured from all parts of the world. Although there is a healthy rivalry between the Army and Navy air organizations, there is at the same time a spirit of cooperation and a mutual understanding of each other's problems that serve to prevent unnecessary duplication in technical developments in aeronautics.

Much of the fundamental research work of the committee has grown out of requests received from the Army and Navy for the study by the committee of particular problems encountered in the services, and in connection with this work the committee desires to give special recognition to the splendid spirit of cooperation of the two services with the committee. Each service has placed at the disposal of the committee airplanes and engines required for research purposes, and has otherwise aided in every practical way in the conduct of scientific investigations by the committee. Without this cooperation the committee could not have prosecuted successfully many of its investigations that have made for progress in aircraft development. The committee desires especially to acknowledge the many courtesies extended by the Army authorities at Langley Field, where the committee's laboratories are located, and by the naval authorities at the Hampton Roads naval air station.

INVESTIGATIONS UNDERTAKEN FOR THE ARMY AND THE NAVY

As a rule research programs covering fundamental problems demanding solution are prepared by the technical subcommittees and recommended to the executive committee for approval. These programs supply the problems for investigation by the Langley Memorial Aeronautical Laboratory. When, however, the Army Air Corps or the naval Bureau of Aeronautics desires special investigations to be undertaken by the committee, such investigations, upon approval by the executive committee, are added to the current research programs.

The investigations thus under conduct by the committee during the past year for the Army and the Navy may be outlined as follows:

FOR THE AIR CORPS OF THE ARMY

Full-scale investigation of different wings on the Sperry messenger airplane.
Investigation of the behavior of an airplane in landing and in taking off.
Investigation of the flat spin of the Douglas O-2 airplane.
Comparative wind-tunnel tests of the M-6, M-12, and Clark Y airfoils.
Investigation of pressure distribution over the wing section of a VE-7 airplane.
Investigation of pressure distribution and accelerations on a pursuit type airplane.
Investigation of performance characteristics of the aeromarine variable-thickness and variable-camber wing.
Acceleration readings on the PW-9 airplane.

FOR THE BUREAU OF AERONAUTICS OF THE NAVY DEPARTMENT

Investigation of the effect of fineness ratio on airship models.
Investigation and development of a solid-injection type of aeronautical engine.
Development of supercharger for aircraft engines.
Distribution of loading between wings of biplanes and triplanes.
Flight tests of superchargers.
Effect of varying the aspect ratio and area of wings on the performance of a fighter airplane with a supercharged air-cooled engine.
Investigation of aerodynamic loads on the U. S. S. *Los Angeles*.
Investigation of spoiler aileron control for TS airplane.
Investigation of performance characteristics of DT and CS seaplanes.
Investigation in the variable-density wind tunnel of standard propeller sections with various camber ratios.
Investigation of performance of five propellers in flight.
Investigation of water-pressure distribution on seaplane hulls.
Investigation of the forces on seaplane floats under landing conditions.
Investigation of autorotation on the NB-1 airplane.
Investigation of performance of model air propellers in a free air stream and in front of a VE-7 model.
Propeller tests on an SC-1 airplane.
Determination of the effect of polish on the surface of airfoil models.
Determination of stresses in aircraft in flight.
Effect of various forms of cowling on performance and engine operation of fighter airplane with supercharged air-cooled engine.

USE OF NONGOVERNMENTAL AGENCIES

The various problems on the committee's approved research programs are as a rule assigned to governmental agencies for study and investigation. In cases where the proper study of a problem requires the use of facilities not available in any governmental establishment, or requires the talents of men outside the Government service, the committee contracts directly with the institution or individual best equipped for the study of each such problem to prepare a special report on the subject. Such special reports are published the same as other technical reports of the committee. In this way the committee makes effective use of the facilities of educational institutions and the services of specialists in the scientific study of the problems of flight.

COOPERATION WITH BRITISH AERONAUTICAL RESEARCH COMMITTEE

Cordial relations have existed for the past several years between this committee and the British Aeronautical Research Committee. These have been greatly strengthened by the delivery on four different occasions of the annual Wilbur Wright memorial lecture before the Royal Aeronautical Society of Great Britain, by Americans closely affiliated with the work of this committee. Three members of the National Advisory Committee for Aeronautics—Dr. W. F. Durand, Dr. Joseph S. Ames, and Dr. David W. Taylor—and a member of our subcommittees on aerodynamics and materials for aircraft who later became a member of the advisory committee—Commander J. C. Hunsaker, United States Navy—have had the honor of delivering this lecture. This led to a closer interchange of thought between those interested in aeronautical research in the two countries.

These cordial relations were further strengthened by the visit, in 1925, of the chairman of the British Aeronautical Research Committee to the Langley Memorial Aeronautical Laboratory and to other research laboratories in this country at which the work is coordinated by the National Advisory Committee for Aeronautics. This visit led directly to the request on the part of the British committee for the loan of certain instruments specially designed by this committee for aeronautical research work, which was granted. After completion of their tests of the instruments, the British authorities furnished this committee the information they had obtained, which proved to be very useful.

The research committees of the two countries have cooperated for several years in an attempt to bring about a standardization of wind tunnels so that the results of tests in various tunnels will be strictly comparable. For this purpose models of airships, airplanes, and wing sections first tested by the British committee were sent to this country and tested by this committee. The tests in the variable-density wind tunnel at Langley Field were especially valuable in giving results at values of Reynolds Number comparable with results obtained in full-scale flight tests.

STANDARDIZATION OF WIND–TUNNEL RESULTS

For the past several years a program of tests has been under way in various wind tunnels in this country and abroad on several series of standard models with a view to bringing about, a standardization of wind-tunnel results by a comparison of the results of these tests.

As part of this program, tests have been under way in various wind tunnels on three-cylinder models having a length ratio of 5:1 and four models of the U. S. A. 16 airfoil section having an aspect ratio of 6:1 and lengths varying from 18 to 36 inches. The tests on these models have not yet been completed.

During the past year the program of standardization tests for the wind tunnels of this country has been extended to include tests of three geometrically similar disks 4, 8, and 12 inches in diameter, respectively. These disks have been constructed and have been tested at the Langley Memorial Aeronautical Laboratory, and will later be tested in the wind tunnels at the Washington Navy Yard, the Bureau of Standards, the Massachusetts Institute of Technology, and McCook Field.

On request of the Aeronautical Research Committee of Great Britain, the committee is now testing in its variable-density wind tunnel at Langley Field a model of the R. A. F. 15 wing section on a Bristol fighter airplane, a model of the R. A. F. 19 wing section on a BE–2E airplane, and a model of the R. A. F. 30 section on a Bristol fighter airplane, for comparison with the results of wind-tunnel and full-scale tests conducted on these sections in England.

In response to suggestion of the Aeronautical Research Committee that valuable information might be obtained if a metal propeller model which had been tested in this country in an open-type wind tunnel could be sent to England and tested in one of the closed-type tunnels of the National Physical Laboratory, the committee forwarded to England for this purpose a metal propeller model which had previously been tested in the open-type wind tunnel at Stanford University.

STANDARDIZATION OF AERONAUTICAL SYMBOLS AND ABBREVIATIONS

During the past year the American Engineering Standards Committee has had under way a program for the simplification and standardization of symbols and abbreviations used in technical and scientific fields. This program is being carried out by a sectional committee on scientific and engineering symbols and abbreviations of the standards committee, the sponsors for which are the American Association for the Advancement of Science, the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Society of Mechanical Engineers, and the Society for the Promotion of Engineering Education.

The National Advisory Committee for Aeronautics has cooperated in this project in the preparation of the proposed standard symbols for aeronautics. Dr. Joseph S. Ames, chairman of the executive committee and of the subcommittee on aerodynamics of the National Advisory Committee, acted as chairman of the subcommittee on aeronautics of the sectional committee on scientific and engineering symbols and abbreviations. The following organizations were represented on this subcommittee in addition to the National Advisory Committee for Aeronautics: The Army Air Corps, the Naval Bureau of Aeronautics, the Bureau of Standards, the United States Weather Bureau, the Air Mail Service of the Post Office Department, the American Society of Mechanical Engineers, the Society of Automotive Engineers, and the Society for the Promotion of Engineering Education. A meeting of the subcommittee was held on April 23, 1926, and a list of aeronautical symbols was recommended for approval as American standard. This list is now being considered by the sectional committee.

EXHIBIT AT NATIONAL SESQUICENTENNIAL EXPOSITION

On invitation of the United States commissioner for the National Sesquicentennial Exposition in Philadelphia the committee installed an exhibit in the Transportation Building, where other Government exhibits were installed. The direct expenses involved were defrayed from allotments made by the United States commissioner. The committee's exhibit occupied a prominent position just inside the main entrance of the Transportation Building. It covered an area of approximately 450 square feet. The exhibit was composed mostly of working models illustrating facilities and methods employed in the conduct of aeronautical research in the committee's laboratories at Langley Field, Va. There was a scale model of the variable density wind tunnel; a model showing the working of the control system of an airplane; a model showing why an airplane flies, which illustrated graphically the dynamic reaction of the air upon the wings of an airplane in flight; a model showing the effect of a rotating cylinder in an air stream and illustrating the principle involved in the Flettner rotor ship; an airplane fuselage section showing special research instruments installed to record various flying characteristics of an airplane, and various models showing the distribution of pressure over the surfaces of airplane wings and airship envelopes and controls. There was also a comprehensive photographic display showing the work in progress and the methods and facilities used by the committee at the Langley Memorial Aeronautical Laboratory. Over the exhibit was an inflated spherical balloon 12 feet in diameter.

The exhibit was one of the first Government exhibits installed and opened for inspection, and because of the public interest in aeronautics and the fact that many of the models could be operated by the visitor himself by pressing buttons, the exhibit proved to be popular to such an extent that visitors kept the working models in nearly continuous operation.

The general message conveyed to the public by the committee's exhibit was that there is an agency in the Government devoted to the study of the fundamental problems of flight and that the National Advisory Committee for Aeronautics supervises and conducts scientific research in aeronautics.

PART III

REPORTS OF TECHNICAL COMMITTEES

REPORT OF COMMITTEE ON AERODYNAMICS

ORGANIZATION

The committee on aerodynamics is at present composed of the following members:

Dr. Joseph S. Ames, Johns Hopkins University, chairman.
Capt. H. C. Richardson, United States Navy, vice chairman.
Dr. L. J. Briggs, Bureau of Standards.
Lieut. Ernest W. Dichman, United States Army, matériel division, Air Corps, McCook Field.
Lieut. W. S. Diehl, United States Navy.
Prof. Alexander Klemin, Department of Commerce.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Maj. Leslie MacDill, United States Army, matériel division, Air Corps, McCook Field.
Prof. Charles F. Marvin, Weather Bureau.
Dr. Max M. Munk, National Advisory Committee for Aeronautics.
Hon. Edward P. Warner, Assistant Secretary of the Navy for Aeronautics.
Dr. A. F. Zahm, construction department, Washington Navy Yard.

FUNCTIONS

The functions of the committee on aerodynamics are as follows:

1. To determine what problems in theoretical and experimental aerodynamics are the most important for investigation by governmental and private agencies.
2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding aerodynamic investigations and developments, in progress or proposed.
4. To direct and conduct research in experimental aerodynamics in such laboratory or laboratories as may be placed either in whole or in part under its direction.
5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

The committee on aerodynamics, by reason of the representation of the various organizations interested in aeronautics, is in close contact with all aerodynamical work being carried out in the United States. In this way the current work of each organization is made known to all, thus preventing duplication of effort. Also all research work is stimulated by the prompt distribution of new ideas and new results, which add greatly to the efficient conduction of aerodynamic research. The committee keeps the research workers in this country supplied with information on all European progress in aerodynamics by means of a foreign representative who is in close touch with all aeronautical activities in Europe. This direct information is supplemented by the translation and circulation of copies of the more important foreign reports and articles.

The committee on aerodynamics has direct control of the aerodynamical research conducted at Langley Field, certain propeller research conducted at Stanford University under the supervision of Dr. W. F. Durand, and a number of special investigations conducted at the Bureau of Standards. The aerodynamical investigations undertaken at the Washington Navy Yard, the matériel division of the Army Air Corps at McCook Field, the Bureau of Standards, and the Massachusetts Institute of Technology are reported to the committee on aerodynamics.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

ATMOSPHERIC WIND TUNNEL.—*Airfoils.*—During the past year models of the N. A. C. A. 81, N. A. C. A. 81–J, Clark Y, M–6, and M–12 airfoils were tested for lift, drag, and pitching moments. In addition, two wing models of particular interest were tested. The first had a section developed by Professor Witoszynski to give a high lift. The second model had the U. S. A. 27 section with protuberances added to the upper surface. The purpose of the protuberances was to lower the induced drag by reducing the lateral flow of air, but the tests showed only a uniform increase in profile drag and no reduction of induced drag.

The results of the biplane-triplane tests made last year were reported for publication.

The magnitude and distribution of aerodynamic pressures was determined on a model of the upper wing of the Fokker D–VII airplane. This model was equipped with an aileron of the overhanging balanced type and unusually large pressures were observed on this overhanging portion, indicating that specifications for the sand loading of this type of aileron should be changed. The effect of a "spoiler" on the pressures over the wing was also investigated with this model. The results showed the spoiler flaps to be a very effective means of producing large rolling moments through the "spoiling" of the lift.

A model of a tapered and twisted thick wing (N. A. C. A. 81–J) was tested to determine the effect of twist on the distribution of lift along the span. This research is still in progress.

A model of the PW–9 wing cellule was designed and constructed for pressure distribution tests. These tests will be made in cooperation with the flight research section to compare with similar pressure-distribution tests on the full-scale airplane.

Investigation of spins.—A number of tests have been made during the past year on a model of the Boeing NB–1 airplane in an investigation of its spinning characteristics. These tests which were made at the request of the Bureau of Aeronautics, consisted chiefly of autorotation tests. In order to simulate as closely as practicable a true spin, it was necessary to construct a specially designed holder which allowed the model to rotate freely with a limited degree of freedom in pitch and yaw. Observations were made on the autorotation rates and angles for various model conditions, wind speeds, angles, etc. In particular, studies were made of the effects of changing the c. g. location, the gap, the size of the vertical tail surfaces, and the location of the vertical tail surfaces.

The tests on the NB–1 were followed by somewhat similar series of tests on a model of the Douglas O–2 airplane for the Army Air Corps. In the O–2 tests the investigation was extended to the effects of aileron settings, flap settings, and stagger on the autorotation rates and angles. It was found that a definite reduction in autorotation range and rate follows the use of differential ailerons, upturned flaps, or stagger in the form of sweepback of the lower wing.

It became increasingly evident during the NB–1 and O–2 tests that the restrictions necessarily imposed in this type of test are sufficient to prevent a duplication of the full-scale spin. Analyses of the wind-tunnel and the free-flight test data showed that precessional moments play a very important part. It was therefore concluded that the wind tunnel could best be used for quantitative determinations of the effects of given modifications on the autorotation rates and angles, while the spin itself could best be studied in a "dropping" test. For the dropping test a scale model is constructed of balsa wood in such a manner that its loading and mass distribution can be adjusted to correspond to any desired condition within reasonable limits. Such a model, when dropped in still air from a considerable altitude—in the present case from the top of an airship shed—very closely duplicates the motion of the full-scale airplane. The dropping tests which have been made to date have given very satisfactory results and appear to be an excellent method of extending the wind-tunnel investigations.

Miscellaneous.—The resistances of three geometrically similar disks were measured for the purpose of standardization of wind tunnels. The same disks are to be tested in other tunnels with a view to their standardization.

The investigation of the forces on rotating cylinders at large ratios of peripheral speed to air speed was concluded.

The results of the tests on flapping fabric have been completely analyzed.

As in the past, instruments for tunnel and flight research have been calibrated and checked in the wind tunnel.

VARIABLE-DENSITY WIND TUNNEL.—With the exception of one or two short periods of minor repair, this tunnel has been in operation through the entire year. Seventy tests, comprising 220 runs, were completed—43 tests on airfoils, 11 on airplane models, 4 on airship models, and 22 on air flow, calibration, and work of a similar nature.

Tunnel wall-interference tests.—Tests were made in the tunnel on five airfoils of the N. A. C. A. M–6 section having different aspect ratios to determine the effect of the tunnel walls on the airfoil characteritics. Further tests using the R. A. F. 19 airfoil section are being made to check the results of the above tests. A report covering the entirere search will be published.

A transverse cross-sectional survey of the air flow at six pressures was made along three diameters at the test section. Particular attention was given to the dynamic pressures close to the wall. The results of this survey were then utilized in determining the theoretical effect of the flow structure. Further work on the theoretical effect is being done.

Sperry messenger airplane model.—Tests were completed on this model fully rigged, using six sets of wings of different section (U. S. A. 5, U. S. A. 27, U. S. A. 35B, R. A. F. 15, Clark Y, and Göttingen 387); the model was also tested with and without a propeller (to scale) at five different pressures ranging from 1 to 20 atmospheres. A report of this work is in preparation.

A. D. C. (Upson) airship model.—A series of tests was completed on this model through a complete pressure range (1 to 20 atmospheres) under the following conditions: Bare hull, hull with car and fins, and hull completely rigged as the MC–2, all at zero angle of pitch; and hull completely rigged at 10 degrees angle of pitch. The resistance of the bare hull was found to be only 40 per cent that of the fully rigged airship. At the maximum pressure the Reynolds Number was equivalent to that of the airship flying at one-quarter cruising speed.

U. S. N. propeller sections.—Six airfoils generated from sections of the United States Navy standard propeller form were tested at 1 and 20 atmospheres density. These sections occur at various radii of a propeller blade. The results obtained are of special interest because of the opportunity for the study of scale effect on a family of airfoil sections having different thickness ratios. A report on these tests has been completed.

N. A. C. A. M–6 and M–12 airfoils with flaps.—A series of tests is now under way to determine the lift, drag, and pitching moment of the N. A. C. A. M–6 and M–12 airfoils with flaps of various sizes and at various flap angles. On these tests the angle-of-attack range is being extended to +48° to determine the aerodynamic characteristics past the burble point. The tests on a 6 by 36 inch M–6 airfoil have been completed. The model was equipped with 20 per cent flaps and ailerons. These were set at seven angles and airfoil characteristics determined. The center of pressure travel was computed for the entire wing under these various conditions.

Miscellaneous.—Improvements in wind-tunnel technique are being continually made. Experiments in the use of plaster-of-Paris airfoils have been conducted. The effects of surface texture and of irregularities in models are being studied.

Several miscellaneous airfoil models have been tested and reported upon, as follows: Clark Y, Witoszynski B–47, N. A. C. A. M–12, N. A. C. A. CYH, R. A. F. 15, N. A. C. A. 81 N. A. C. A. 81–J, R. A. F. 19, and Göttingen 398.

PROPELLER RESEARCH EQUIPMENT.—The committee has under construction at the Langley Memorial Aeronautical Laboratory a new piece of equipment known as the propeller research equipment. Its purpose is to make tests on full-sized airplane propellers under flying conditions. It consists of a wind tunnel of the open-throat type large enough to permit the mounting of a full-sized airplane fuselage with its engine and propeller.

The throat diameter of this tunnel is 20 feet, and an air velocity of 100 miles per hour at the throat is expected. The experimental chamber is 50 feet by 60 feet in plan and 50 feet high. The driving propeller is to be 28 feet in diameter and to have eight cast-aluminum blades. It is to be driven by two Diesel engines of 1,000 rated horsepower each. The airplane to be tested will be mounted on a balance by which the torque and thrust may be measured. Lift, drag, and pitching moments may be measured also if desired. There is also to be a special test fuselage provided with a dynamometer for measuring engine torque. This is for checking results obtained on the regular balance.

It will be possible with this equipment to make tests which could not heretofore be made on engines, engine cowlings, and other full-sized airplane parts, as well as tests of propellers under actual flying conditions.

The main structure of this equipment has been completed. The power plant is now under construction. It is expected that the tunnel will be put in operation in a few months.

FLIGHT RESEARCH.—*Airships.*—The most extensive research conducted at the Langley Memorial Aeronautical Laboratory during the last year, and probably the most complete of its kind, was the series of tests conducted on the U. S. S. *Los Angeles* to find the stresses and loads experienced by a rigid-type airship in maneuvering flight and in flight in gusty air. The loads were determined from pressure measurements made simultaneously at approximately 300 points on the tail surfaces, hull, and car, together with acceleration tests and turning trials. At the same time stress measurements were made by the Bureau of Aeronautics of the stresses in a number of the main structural members of the airship. By means of instruments recording other measurements, such as air speed, angle of yaw, angular velocity, and control position, the motion of the airship was determined. Since all the measurements were simultaneous and continuous for a period of time, the result is a history of the motion of the airship through the air, the pressures and loads experienced during this motion, and the stresses imposed in the structure by the loads experienced. The large amount of data obtained has not as yet been arranged in the form of a report, but such results as have been worked up show definitely that the loadings and stresses experienced in gusts greatly exceed those in maneuvers.

Airplanes.—Within the year a research has been completed in which a study was made of the effect of the proximity of the ground upon the aerodynamic characteristics of a full-scale airplane. The tests conducted consisted in the determination of the lift and drag characteristics of an airplane close to the ground and at an altitude sufficient to avoid any possibility of "ground effect." It was found that the drag of the airplane was materially reduced upon approaching the ground and that the reduction might be satisfactorily calculated according to theoretical formulæ. In continuation of this work, smoke-flow photographs and pressure-distribution measurements were made to study the type of air flow over the wings when the drag was reduced, but because of excessive experimental difficulties the work was discontinued for the time being.

The information obtained last year on the landing and take-off characteristics of nine of the service type airplanes in use by the Army Air Corps has been studied and analyzed, and formulæ derived for determining the distance required for the ground run of an airplane in wind of any velocity. By use of the formulæ the ground run of any airplane of normal design can be calculated to a reasonably close approximation, thus enabling the estimating of this characteristic in a proposed design, and also providing data for estimation of the requisite size of proposed landing fields.

The aerodynamic characteristics of an airplane equipped with several different sets of wings has been determined. The tests were conducted on a Sperry messenger airplane equipped successively with R. A. F. 15, U. S. A. 5, U. S. A. 27, and Göttingen–387 wings, and the lift and drag characteristics of the airplane with each set of wings determined throughout the flight range of angle of attack. The results establish the comparative characteristics of these airfoils free from scale effect, and furthermore provide a standard for comparison with wind-tunnel tests.

A complete investigation is in progress of the air-pressure distribution over the wings and tail surfaces of a high-speed pursuit airplane. Together with the pressure measurements, accelerometer readings are made of the accelerations of the wing tips, tail surfaces, and center of gravity of the airplane, in order to determine the occurrence of the inertia loads at these places with respect to air loads and also the correlation of the inertia loads at the wing tips and tail surfaces with those at the center of gravity. Since the investigation is being conducted to provide the data necessary for a revision of the methods of load computations and loading specifications, the investigation includes violent maneuvers to make certain the obtaining of the most critical loadings.

The work on seaplanes during the year has been on the problem of measuring the pressures and forces experienced by a seaplane hull or pontoon at landing or while taxiing. For this type of research an apparatus has been developed and constructed with which it is possible to measure the water pressures over the bottom of a pontoon. The apparatus is of the recording type and is capable of recording continuously over a period of time the pressures that occur as a result of the impact at landing and the impact of waves striking the hull. Since these pressures exist for only a very short time it has been necessary to construct the apparatus to record pressures one one-hundredth of a second in duration.

In addition to the water-pressure distribution tests the investigation includes the determination of the magnitude and direction of the resultant force on the seaplane. This is accomplished by means of three 3-component accelerometers mounted, respectively, in the pontoon nose, pontoon tail, and fuselage of the seaplane which measure the magnitude and direction of the forces experienced at each place. A knowledge of this resultant force is required for use in the design of the pontoon bracing. Both researches are in progress at present.

A study of the possible increase in lateral control by the use of spoiler flaps acting in conjunction with ailerons has been completed. The angular velocities and accelerations in roll and in yaw of a TS airplane fitted with spoiler gear were measured and the change of altitude was determined when the spoiler gear was employed and when the ailerons alone were used. The results showed that this particular type of gear offered little if any improvement over the usual aileron control.

A knowledge of the character of gusts and the velocity of the air in them is of importance in studying the behavior of airplanes in landing, but is of even greater importance in the study of the forces on airships encountering gusts. As a preliminary step in the study of gusts an apparatus has been installed at the laboratory to measure the velocity of air in gusty and stormy weather. With the apparatus a series of measurements are taken over a period of time when the weather is stormy or the air particularly bumby and the resulting information studied to determine the possibility of forecasting the nature of gusts to be expected in different conditions of weather.

For the better study of the maneuverability of airplanes, particularly in spins, experiments were conducted with a specially constructed camera obscura with which the maneuvers were photographed from the ground. As yet the development is in a preliminary stage, but the results obtained indicate the practicability of this method of studying maneuvers.

Propellers.—The flight tests of four experimental propellers on the VE–7 airplane, mentioned in last year's report, are practically completed. Wind-tunnel tests of similar model propellers are being conducted and the results will be compared with flight results to establish the applicability of the former to full-scale use and if possible determine the correction necessary.

Several propellers are being calibrated to be used in determining the torque characteristics of supercharged engines in flight.

Performance.—The performance tests mentioned in last year's report are still in progress on the DT and CS airplanes to determine the possible improvement in the performance of these airplanes equipped with Wright T–2 and T–3 engines when the use of (*a*) overcompression, (*b*) superchargers, (*c*) gears, or (*d*) combination of gears with overcompression or supercharging, is resorted to. A series of performance tests of a DH–9 airplane equipped with a hub-type engine dynamometer has been completed. These tests were conducted for the dual purpose of testing the practicability of the dynamometer and of obtaining data on the variation of engine power with altitude.

ANALYTICAL SECTION.—During the past year the following investigations were undertaken.

Pressure loss in tubes.—This research, which had been begun during the previous year, was concluded. Experiments in the laboratory and tests on an airplane in flight showed that the pressure loss is negligible in apparatus as now installed for pressure-distribution tests.

Simple formulæ for determining the error caused by mass forces in connecting tubes as used in tests on large aircraft such as airships were worked out and the limits wherein friction and elasticity cause no appreciable error of the pressure reading were laid down from experimental curves. However, considerable mathematical analysis failed to reveal any formulæ for computing the pressure errors, if any exist.

Influence of the wind-tunnel flow structure on the wing air forces.—This investigation deals with the modification of the air forces on an airfoil in a wind tunnel caused by an uneven distribution of the flow velocity over the throat cross section.

An analytical method suitable for the investigation of this and other problems was developed and was applied to the study of flow structure in the variable-density wind tunnel. The research will be completed by combining the analytical and experimental results.

Study of orifices.—A study has been begun of the relation between the size of the orifice used in pressure-distribution measurements and the size and form of the surface over which the pressure is being measured. A wind tunnel with a 6-inch throat diameter was built and put in operation to supplement the analytical work by researches of a physical character. Although it has been in operation only a part of the year, there has been completed an investigation of one phase of the more general problem of the measurement of air pressures. This consisted in the determination of the effect of orifice size on the pressure distribution around a circular cylinder. The results show that orifices now being used on aircraft and models in making pressure-distribution measurements do not introduce appreciable errors in the pressure readings.

INSTRUMENT RESEARCH AND DEVELOPMENT.—A considerable amount of work has been done during the year in adapting instruments previously constructed to meet the more exacting requirements of the tests recently undertaken by this laboratory. The changes made in the design and operation of the instruments have made the procurement of valuable test data possible.

An example of work of this nature is the instruments which were prepared for a series of flight tests with the U. S. S. *Los Angeles*. Here the physical measurements taken were extremely small and changed in value slowly, the pressures being of the order of 1 inch of water. The pressure-recording instruments used on this test included three multiple recording manometers. Each manometer contained 60 complete differential pressure gauges, which simultaneously recorded upon a sensitized film pressures at various points on the airship. The pressure records were synchronized with other records by electrically operated chronometers. The same recording instruments have been modified for a somewhat similar test on the Boeing PW–9 airplane, in which the pressures measured will probably be one hundred times greater than on the lighter-than-air craft and will change very rapidly in value. Such wide changes of characteristics illustrate the adaptability of these special research instruments.

The adaptation of two 30-capsule type recording manometers to record impact pressures on seaplane pontoons in landing was carried out successfully by converting the pressure capsules to electric recording instruments. There are 15 complete electrical units on each recorder, each unit consisting of a solenoid-operated optical system, connected electrically to a pressure-operated step-by-step rheostat secured to the pontoon being tested. Impact pressures of one one-hundred-and-fiftieth second duration can be recorded.

During the past year a number of the standard recording instruments were duplicated, such as recording altimeters, automatic observers, flight path recorders, and recording accelerometers. The optical and damping systems of the three-component type recording accelerometer were redesigned to permit of easier adjustment. The opportunity was taken on each instrument duplicated to incorporate improvements that would increase its reliability and usefulness.

A fixture for calibrating accelerometers and turn recorders was constructed and placed in service. Through its use the time required to make routine calibrations of these instruments is materially reduced and at the same time accurate calibrations may be made throughout the entire range of accelerations and angular velocities encountered by aircraft in free flight. In addition, the apparatus has been used to investigate the time lag and damping of accelerometers and it is intended to extend this investigation to turn recorders.

A large liquid manometer having 30 glass tubes was constructed for use in connection with wind-tunnel work. With this instrument permanent records of pressures are obtained on photostat paper. A second manometer of this type having 116 glass tubes is now under construction. An automatic yaw observer, a new continuous recording film drum, and special control reduction apparatus for use in recording position of airship controls were developed for use on the test of the U. S. S. *Los Angeles*.

Much valuable work was done on the elimination of temperature effect on recording instruments by the use of the altitude chamber which was constructed last year. Investigations of temperature and pressure effects have been made on practically all of the recording research instruments now in use at this laboratory. Changes have been made, where possible, in instrument construction to minimize this effect. However, in nearly all tests the temperature correction is determined before the instrument is installed, and a check is made after the test. In connection with this work a study of the change in viscosity with temperature of a number of oils suitable for instrument damping is under way. It is expected that an oil or a combination of oils will be found that will be satisfactory at the low temperatures encountered in some of the flight tests. More work remains to be done on this investigation before any definite conclusions can be drawn. The altitude chamber has been valuable in the investigation, at reduced pressure and temperature, of the performance of magnetos and spark plugs before their installation in airplanes for high-altitude tests.

An investigation is now in progress to determine the practicability of the use of carbon disks in conjunction with a cathode-ray oscillograph as an engine indicator for high-speed aircraft engines. Such an indicator would eliminate the inertia errors now present in the majority of such indicators and would be a means of obtaining the much-needed information as to the true pressures encountered in high-speed internal-combustion engines.

Considerable study has been given to the design and construction of a fuel-flow recorder for power-plant use. The work was undertaken for the purpose of making an instrument that would record the rate of fuel consumption of an aircraft engine during flight, thereby giving information needed in the investigation of engine characteristics. A Venturi type, a vane type, and a diaphragm type meter have so far been investigated. The latter type has proved the most satisfactory. It consists of a metal case which is divided into two compartments of different volume by a metal diaphragm. The fuel is directed through both compartments in its flow, thereby creating a difference in pressure which deflects the diaphragm. An optical system is provided to record the diaphragm deflection upon a moving film. However, more work remains to be done on this type of meter with a view to eliminating the effect of vibration.

At the request of the Bureau of Aeronautics a recording accelerometer was prepared and a series of tests made at the naval aircraft factory to instruct their personnel in taking records of catapult acceleration and deceleration.

STANFORD UNIVERSITY

The following investigations have been completed during the past year at the Stanford University aerodynamic laboratory:

(1) Tests of three model propellers in a free wind stream and in combination with a model VE–7 airplane. Two of the model propellers were of duralumin, one two-bladed and the other three-bladed, the driving face of the blades being concave or cambered somewhat more than the conventional design. The third model was of pressed steel (two-bladed) and provided with cloth fairing.

(2) Tests of a model propeller with symmetrical blade sections. The sections used in these tests were Göttingen airfoil No. 409.

(3) Tests of five metal model propellers of adjustable pitch. These models consisted of a single steel hub and five pairs of duralumin blades. Each set of blades was carried through complete tests with six separate angular settings, thus making in all 30 models.

Aeronautical activities at Stanford University, both in research and instruction, will be increased as a result of a grant received from the Daniel Guggenheim fund for the promotion of aeronautics. The wind tunnel will be moved from its present situation in a temporary building to a permanent location, and additional facilities and apparatus provided for research, including a wire aerodynamic balance in addition to the special propeller balance which has been in use for several years in the present laboratory. The grant will also provide for two new professorships—one in aerodynamics and one in design and construction. These two new chairs, together with the strengthened and improved laboratory facilities, are expected to lay a foundation for a well-balanced and thorough course of training in aeronautical engineering, as well as secure considerable extension in the amount and scope of the research work carried on.

WASHINGTON NAVY YARD

Airplane models.—During the past year the 8-foot wind tunnel at the Washington Navy Yard has been employed largely in testing airplane models. In all, 31 complete tests in pitch and yaw were made on 18 different designs. Eleven of these models accounting for 20 of the tests were Bureau of Aeronautics design studies. The remaining seven models were chiefly made up of service types which were tested for particular requirements.

In continuance of past practice four design studies were tested in both the landplane and the seaplane arrangement, while two models were tested with two wing sections and one model was tested with three wing sections. These tests have supplied data of considerable interest and value to the bureau, the most important feature probably being the high efficiency of the Göttingen–398 wing section and its modifications in biplane arrangements. The magnitude of the improvement as shown by thoroughly checked wind-tunnel tests is approximately 10 per cent in L/D at all normal angles. Flight tests are to be made at an early date to verify the wind-tunnel indications. Analyses of the tests on landplane and seaplane arrangements, which are now under way, indicate a remarkably uniform difference in parasite area, running from 1 to 1½ square feet greater for the seaplane than for the landplane.

Another series of tests of great interest was made on the PN–9 model, in which wing incidences of 2°, 4°, and 6° to the thrust line were used. It was found that increasing the incidence from the original value of 2° to 4° (the value adopted for the PN–10) gave a marked improvement in take-off and cruising characteristics, with an unexpected increase in static stability.

Other tests included a study of the effect of flaps on the OL–1, tests on the UO–1 model through 360° in pitch, and the test of a biplane in which the lower wing had considerable taper and dihedral, so that its outer tip was attached to the upper wing.

Airfoils and wings.—Owing to the press of urgent airplane model tests, only four airfoils and one wing model have been tested during the past year. However, a number of airfoil tests have been projected and the models are now awaiting tests at a convenient opportunity. As explained in the previous report, these sections have been developed from standard sections with a view to producing desirable structural characteristics while retaining desirable aerodynamic characteristics.

Miscellaneous tests.—Tests have been made in pitch and yaw and at various speeds on 14 seaplane float models. These tests were made in the 4 by 4 foot wind tunnel and cover, in connection with previous tests, about every type of float now used or proposed for use. A report of the tests will be submitted later to the National Advisory Committee for publication.

The tests on fuselages have also been extended along the lines followed previously. A total of 12 models have now been tested and a report of these tests will also be submitted for publication later.

Three models of a special Heinrich wing radiator for racing airplanes were given the usual radiator tests while mounted on a dummy full-scale wing. Additional tests on the wing alone gave the resistance added by the radiator and indicate that while this type of radiator has much less resistance than the cellular type, it probably has considerably more resistance than the true wing type. Tests were to be made on a section of a wing radiator to determine this resistance, but it has not been practicable to obtain a satisfactory model.

Tests have been started on a series of 12 struts, using the Navy No. 1 section. These tests will cover the effect of fineness ratio, scale, and trailing-edge radius.

Two models of the *MC-2* airship were given tests in pitch and yaw and for damping moments. It was originally intended to make the complete series of tests on the first model, but a very large scale effect was found in the damping tests, necessitating the construction of a second and larger model from which satisfactory data were secured.

Wind-tunnel equipment.—Only one important change has been made to the wind tunnels during the past year. The chain drive for the 4 by 4 foot tunnel has been replaced by a direct drive, which eliminates considerable vibration while giving steadier operation at higher speeds.

During the tests on fuselages and floats a new type of stream-line spindle was used with very satisfactory results. This spindle replaces the conventional tapered cylindrical spindle and not only reduces the correction to a very low figure but also practically eliminates mutual interference.

BUREAU OF STANDARDS

Wind-tunnel investigations.—As mentioned in the last annual report of the committee, measurements have been made at Edgewood Arsenal of the pressure distribution over six airfoils ranging in camber ratio from 0.10 to 0.20 at speeds from 0.5 to 1.08 times the speed of sound. During the past year the necessary computations have been made and the results have been presented to the committee and accepted for publication as a technical report. An interesting result of the tests was a limiting value of the decrease in pressure on the upper surface of any airfoil of about one-half to one atmosphere.

Apparatus is now being installed at the Bureau of Standards of capacity comparable to that at Edgewood Arsenal for conducting investigations at high speeds. It is expected to continue work on the design of expanding nozzles to give speeds much greater than the speed of sound and a stream free from standing pressure waves. Work will also be carried out on airfoils, especially force measurements on thin airfoils.

Measurements have been made of the aerodynamical characteristics of several aircraft bombs for the Ordnance Department of the Army. The bomb fins were designed by the method developed at the bureau, and in all cases the observed center of pressure was the same as the computed center of pressure within about 3 per cent of the bomb length. A study was made of the comparative effectiveness of 4, 6, and 8 fins. Four fins are most favorable when the dimensions are kept within a prism containing the bomb body.

The investigation of turbulence in wind tunnels has been continued in cooperation with the National Advisory Committee for Aeronautics. Various experiments have been carried out with hot wire instruments for measuring variations in air speed and with small direction vanes for measuring variations in wind direction. Neither of the instruments has yet been developed to give satisfactory measurements of variations the frequency of which is greater than about 10 per second.

The measurements of the distribution of pressure over the surface of a square base prism, 8 by 8 by 24 inches, have been published as Scientific Paper 523 of the Bureau of Standards. During the past year measurements have been made of the total forces on square-base prisms of several heights in continuation of the work on wind pressures on structures. Measurements of the distribution of pressure over two cylinders, one 8 inches in diameter and 60 inches long, the other 12.6 inches in diameter and 60 inches long, have been completed and the results are now being prepared for publication.

A large number of measurements have been made on an airplane model submitted by Mr. Charles Ward Hall. The measurements included pitching, rolling, and yawing moments with various control settings on the original model and on several modifications of the original model.

Aeronautic instrument investigations.—The research and development work of the aeronautic instruments section of the Bureau of Standards has, as in other years, been largely in cooperation with the National Advisory Committee for Aeronautics, the Bureau of Aeronautics of the Navy, the Air Corps of the Army, and other Government departments.

The instruments constructed for the National Advisory Committee for Aeronautics include three electric resistance thermometers and two galvanometer units each containing three galvanometers. The electric thermometers are for measuring the free air temperatures in flight to an accuracy of less that 1° F. in the range −40° to +90° F. The galvonometer units contain small, highly sensitive galvanometers of the type developed during the previous year. Rubber diaphragms of unusually good aging characteristics have been inserted in six Ogilvie air-speed meters which are now being given service tests at the Langley Memorial Aeronautical Laboratory.

An electric type air-speed meter of the frequency type has been developed and constructed for the Army Air Corps. The output of an alternating current generator, driven by a propeller in the air stream, is measured by an induction type indicator which is calibrated in air speed.

A superheat meter and a gas-pressure alarm, both for use on the U. S. S. *Los Angeles*, were constructed for the Bureau of Aeronautics. The gas-pressure alarm is an improvement of an earlier model constructed at this bureau. Considerable work of an experimental nature has been under way on earth inductor compasses which has resulted, among other things, in reducing greatly the trouble inherent in the use of brushes. Rattling tests have been conducted on specimens of duralumin containing patches riveted in the same manner as for the proposed all-metal airship.

The equipment of an altitude chamber in which both the temperature and pressure can be reduced has been in progress. The chamber is of such size as to admit two observers and the instruments under test.

Altitude-pressure tables based on the United States standard atmosphere have been prepared with especial reference for use in determining altitudes. These supplement the tables given in Technical Report No. 218 and are being issued as Technical Report No. 246.

A summary of the current experimental work on the friction of instrument bearings and pivots has been prepared for the Army Air Corps. A report on the theory of the deflection, temperature errors, and lag of capillary type rate-of-climb indicators has been under preparation during the past year for the Bureau of Aeronautics.

Assistance has been given the Army Air Corps and the Bureau of Aeronautics of the Navy in standardizing the specifications for aircraft instruments. About 20 specifications were rewritten and submitted to the air services. The revisions related largely to the tests and tolerances.

The theoretical and experimental work on statistical hysteresis has been summarized in a report now in press as a Bureau of Standards scientific paper. A new property of materials, the statical hysteresis modulus, is propoesd and evaluated for Armco iron. An extension of this work promises data important to designers of precision instruments.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Wind tunnels and equipment.—No radical changes have been made in the wind tunnels or equipment. A new wire balance with automatic beams of light construction has been designed for the 4-foot wind tunnel. The beams have been built.

Propeller interference tests.—The tests commenced during 1925 in the 7½-foot wind tunnel to find propeller effects on a one-fourth scale DH–4B model have been continued throughout the year. Complete measurements have been made at angles of attack from 0° to 20° of the forces and moments on the model due to various slip streams, the effect of the model on the propeller, the increase in control moments due to slip stream, the downwash caused by the propeller, and the slip-stream velocity in so far as it affects the force on the horizontal tail. Following the tests with the regular DH–4B fuselage, some investigation has been carried on of the effect of rounding the fuselage with and without a spinner on the propeller.

Miscellaneous tests.—A few complete models of airplanes have been tested in the 4-foot tunnel. Other researches in the tunnel include an investigation of wing locations in multiplanes, air-flow tests of several radiator cores, and some work on the cooling capacity of a radiator unit. Student researches included ground effect on control moments, the air force on bridge trusses, and the effect of hinge gap on control forces.

M'COOK FIELD

General.—Only about 50 routine tests were made in the McCook Field 5-foot wind tunnel last year. The work done has been largely of the nature of improvements in apparatus and technique.

High-force tests.—Use of the wire balance has been inaugurated for routine work on 6 by 36 inch airfoils at 120 miles per hour, and on model airplanes at whatever velocity the model will stand. The high forces obtained, reaching 250 pounds, have introduced novel problems, for example, some metal airfoils bow up in the middle; in one case the steel "skid" carrying the pitching moment force deflected sufficiently to take a permanent set. It has been necessary to adopt optical methods of aligning the model during tests, since wire stretch becomes large at high velocities, and ordinary mechanical methods are insufficient. By means of telescopic model alignment, the use of self-balancing scales has been justified, especially for the higher velocities. Travel of the scale pans is taken care of simultaneously with wire stretch by raising and lowering the platforms on which the scales rest. The motion is derived from electric motors under control, by means of push buttons, of the telescope operator.

Low-force tests.—The N. P. L. type balance is retained for low-speed tests under 60 miles per hour, since at these lower speeds the wire balance is less accurate and less convenient.

It has been necessary to reopen the question of "spindle and guard corrections," and new values have been determined which seem to be more satisfactory than the conventional values originated at the National Physical Laboratory. The correction was found sufficient to jeopardize one series of tests made to determine the effect of size of airfoil; in this series models from 1 by 6 inches to 6 by 36 inches were under examination and ultimately required the adoption of a stream-line wire in lieu of a spindle.

Pressure drops through Goodyear-Zeppelin radiator.—In order to predict the energy loss in a tunnel-type radiator proposed by the Goodyear-Zeppelin Corporation for airship use, a dummy section representing the radiator was connected to the 14-inch wind tunnel, air was caused to flow through the section, and the pressure drop under various conditions was observed. The purpose of the data was to predict the amount of flow to be expected through the radiator, rather than to measure resistance or heat transmission.

Surface-flow pictures.—Many photographs have been taken of the air flow at the surface of various models, using a method borrowed from the General Electric steam turbine laboratories and developed for use at low velocities. This method involves painting the model with a mixture of lampblack and kerosene; the air flow then records its direction by scouring fine channels in the pigment; "surface lines" result and may be photographed at leisure. A study has been made of the divergence between this "surface" flow and the adjacent flow outside the boundary layer.

Officers' school.—The usual period required by the McCook Field officers' school was devoted to instructing 13 officers in wind-tunnel procedure.

Removal to Wright Field.—In anticipation of moving the 5-foot and 14-inch tunnels to Wright Field in 1927, new construction has been discontinued. The propeller dynamometer, though completed, has not been put into use, and various other development projects have been postponed.

Test of model of engine-dynamometer stand.—To facilitate design of ventilation apparatus for the engine test laboratory proposed for Wright Field, two models have been tested in the 14-inch tunnel. One was an exhaust flue actuated by an air jet; the other was a cooling-blast system.

Service tests.—Service tests have included the following:

1/24-scale model, long distance reconnaissance (on wire balance at 100 miles per hour).
1/50-scale model, Huff-Daland XHB–1 heavy bombardment (on N. P. L. balance at 40 miles per hour).
1/36-scale model, Huff-Daland XLB–1 light bombardment.
1/36-scale model, Douglas C–1 transport.
1/30-scale model, Douglas XNO–1 night observation.
Twenty 3 by 18 inch propeller airfoils at speeds from 30 to 250 miles per hour (N. P. L. and wire balances).
Six 6 by 36 inch air foils on wire balance at 40 to 140 miles per hour, as follows:

STAE–27A.
Clark Y–.
Clark Y–15.
Clark Y–18.
Clark Y–21.
Göttingen–398.

Model of Gligorin rotor wing.
Hinge moments on $\frac{1}{16}$-scale model XHB–1 rudder.
Hinge moments on model of a balanced elevator.
Various instrument calibrations, including rate-of-climb indicators, yaw meters, anemometers, experimental Pitot-static tubes, etc., and a Nipher statis-head orifice.

REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

ORGANIZATION

The committee on power plants for aircraft is at present composed of the following members:

Dr. S. W. Stratton, Massachusetts Institute of Technology, chairman.
George W. Lewis, National Advisory Committee for Aeronautics, vice chairman.
Henry M. Crane, Society of Automotive Engineers.
Prof. Harvey N. Davis, Harvard University.
Dr. H. C. Dickinson Bureau of Standards.
Prof. C. Fayette Taylor, Massachusetts Institute of Technology.
Capt. T. E. Tillinghast, United States Army, matériel division, Air Corps, McCook Field.
Commander E. E. Wilson, United States Navy.

FUNCTIONS

The functions of the committee on power plants for aircraft are as follows:

1. To determine which problems in the field of aeronautic power plant research are the most important for investigation by governmental and private agencies.
2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding aeronautic power plant research in progress or proposed.
4. To direct and conduct research on aeronautic power plant problems in such laboratories as may be placed either in whole or in part under its direction.
5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

By reason of the representation of the Army, the Navy, the Bureau of Standards, and the industry upon this subcommittee, it is possible to maintain close contact with the research work being carried on in this country and to exert an influence toward the expenditure of energy on those problems whose solution appears to be of the greatest importance, as well as to avoid waste of effort due to unnecessary duplication of research.

The committee on power plants for aircraft has direct control of the power plant research conducted at Langley Field and also of special investigations authorized by the committee and conducted at the Bureau of Standards. Other power plant investigations undertaken by the Army Air Corps or the Bureau of Aeronautics are reported upon at the meetings of the committee on power plants for aircraft.

FUEL INJECTION ENGINE.—The performance requirements of aircraft engines are exacting. Maximum power per pound engine weight, minimum fuel consumption per horsepower per hour, and maximum reliability are required. The application of hydraulic injection and compression ignition of fuel oils to aircraft engines not only involves all the problems of the usual heavy, slow-speed oil engine but considerably intensifies them and introduces many new problems because of the combination of high speeds, high mean effective pressures, low fuel consumption, and light weight with reliability required.

The major fundamental problems involved in building a successful fuel-injection engine for aircraft service are, first, the efficient physical and thermal preparation of the fuel to obtain its practically instantaneous autoignition at injection into the engine cylinder; second, the efficient and complete distribution of the fuel throughout the combustion chamber by the use of proper oil spray shapes, atomization, and energies, combustion chamber shapes, and turbulence to obtain its complete uniform mixing, and therefore combustion, with the air in the cylinder early in the power stroke; third, the determination of the effects of a number of engine variables, such as compression ratio, speed, temperatures of the air, water, and oil, and engine design details upon mechanical, volumetric, and thermal efficiencies.

The solutions to these fundamental problems are obtained by conducting systematic investigations in injection hydraulics, on the characteristics of fuels, on the characteristics of oil sprays in dense gases by means of ultra high-speed motion-picture photography, on the bench and engine performance of injection valves, pumps, and miscellaneous oil injection equipment, on the engine performance of cylinders, cylinder heads, and oil injection systems on single-cylinder test engines for various test conditions and engine design details, and by theoretical analyses.

Engine performance—Combustion chamber design.—The study of the effects of combustion chamber design, chiefly as regards shape and turbulence, on engine performance has been continued. This work has been carried on with a single-cylinder Liberty engine base fitted with a special steel cylinder to which the several cylinder heads to be tested are bolted. The effects of compression ratio may be investigated by inserting metal gaskets between the engine base and cylinder or between the cylinder and cylinder head. The cylinder bore is 5 inches and the stroke 7 inches. Standard aircraft engine pistons, connecting rods, and valves are used.

The performance of a flat disk-shaped combustion chamber having one inlet and one exhaust valve in the head, and the injection valve located at the circumference of the combustion chamber, has been determined for speeds up to 1,800 revolutions per minute, various injection rates and injection pressures, and various powers with a compression ratio of 12.7 to 1, and a controlled maximum cylinder pressure of 800 pounds per square inch. The fuel pump used was of the impact type, cam-actuated and fitted with means for timing the injection of the fuel. The injection valve was of the automatic spring-loaded stem type, with an impact surface to direct and atomize the fuel. The performance of this cylinder head with and without directed flow of the inlet air was determined for a speed of 1,500 revolutions per minute. The best results were obtained with an injection valve opening pressure of 1,400 pounds per square inch, a high rate of fuel injection, and with the flow of the inlet air directed to produce turbulence in the cylinder. For full-load conditions, i. e., a fuel weight per cycle giving 15 per cent excess air, and 1,500 revolutions per minute, the indicated mean effective pressure was 82 pounds per square inch and the fuel consumption 0.65 pound per indicated horsepower per hour with the flow of inlet air not directed. With directed flow of the inlet air the indicated mean effective pressure was 99 pounds per square inch and the fuel consumption 0.53 pound per indicated horsepower per hour. At two-thirds load, i. e., two-thirds the fuel weight per cycle at full load, the indicated mean effective pressure was 82 pounds per square inch and the fuel consumption 0.41 pound per indicated horsepower per hour.

The performance of a precombustion or bulb-type cylinder head with the greater part of the clearance volume in the bulb was completed from the previous year for speeds up to 1,800 revolutions per minute, and various powers with a compression ratio of 9.9 and a controlled maximum cylinder pressure of 1,000 pounds per square inch. The orifice between the cylinder and bulb produced moderate turbulence. An eccentric-operated fuel pump and an automatic diaphragm type injection valve were used. A high rate of fuel injection and injection pressures up to 10,000 pounds per square inch were investigated. The indicated mean effective pressure obtained at full load and 1,800 revolutions per minute was 106 pounds per square inch, and the fuel consumption 0.48 pound per indicated horsepower per hour. At two-thirds load, the indicated mean effective pressure was 99 pounds per square inch and the fuel consumption 0.35 pound per indicated horsepower per hour.

The construction of the second bulb-type cylinder head, arranged to permit the investigation of compression ratios up to 15 to 1, and providing for various precombustion chamber volumes and shapes and degrees of turbulence has been completed. The performance of this cylinder head has been determined for a compression ratio of 13.5 to 1, a precombustion chamber volume equal to one-half the clearance volume, speeds from 600 to 1,800 revolutions per minute, maximum cylinder pressures from 500 to 750 pounds per square inch, and a high degree of turbulence. The effects of extending the fuel valve nozzle various distances into the precombustion chamber have been determined. Power performance characteristics have been determined for progressive alterations in the orifice between the cylinder and precombustion chamber. A cam-operated fuel pump and an automatic injection valve having special discharge characteristics and producing extremely fine fuel atomization were used. The best results thus far have been obtained at 1,300 revolutions per minute with the injection valve nozzle extended one-quarter inch into the precombustion chamber, and with the orifice flared to discharge the burning gases from the precombustion chamber so as to produce uniform fuel distribution and a high rate of gas rotation in the cylinder. At full load and 1,600 revolutions per minute, the indicated mean effective pressure was 119 pounds per square inch and the fuel consumption 0.44 pound per indicated horsepower per hour, with 740 pounds per square inch maximum cylinder pressure. The indicated mean effective pressure at two-thirds load was 107 pounds per square inch and the fuel consumption 0.32 pound per indicated horsepower per hour, with 690 pounds per square inch maximum cylinder pressure. At one-third load the indicated mean effective pressure was 65 pounds per square inch and the fuel consumption 0.26 pound per indicated horsepower per hour, with 610 pounds per square inch maximum cylinder pressure.

Engine performance—Engine variables.—The investigation of the effects of a number of engine variables, chiefly compression pressure, injection timing, injection valve opening pressure, and maximum injection pressure or engine power performance, mechanical, volumetric, and thermal efficiencies, is nearly completed for a wide range of conditions. This work has been carried on with the N. A. C. A. Universal test engine which is constructed so that the compression ratio, injection timing, and inlet and exhaust valve timing and lift may be readily varied while the engine is running. The present combustion chamber of this engine is well adapted for and has been used extensively in carburetor engine work. It is pent-roof shaped, however, and no definite turbulence is provided so that complete mixing of the fuel and air in oil engine research is not obtained. A special fuel preheating and atomizing injection valve has been developed and used with an eccentric-operated fuel pump adjusted to give a high rate of fuel injection.

The performance of this cylinder head has been determined for various powers at 1,500 and 1,750 revolutions per minute, with a compression pressure of 360 pounds per square inch and a maximum cylinder pressure of 800 pounds per square inch. The indicated mean effective pressure at full load and 1,750 revolutions per minute was 116 pounds per square inch and the fuel consumption 0.45 pounds per indicated horsepower per hour. At two-thirds load the indicated mean effective pressure was 96 pounds per square inch and the fuel consumption 0.35 pound per indicated horsepower per hour.

The performance of this cylinder head and injection system, for a constant quantity of fuel injected per cycle equal to 83 per cent full load, at 1,500 revolutions per minute, and for compression pressures ranging from 325 to 560 pounds per square inch and a wide range of injection timing and maximum cylinder pressures, has been completed. With a compression pressure of 345 pounds per square inch and the fuel entering the cylinder 2 degrees before top center, the indicated mean effective pressure was 81 pounds per square inch, the fuel consumption 0.54 pounds per indicated horsepower per hour, the maximum cylinder pressure 590 pounds per square inch, and the mechanical efficiency 65 per cent. When the injection timing was advanced to start injection of the fuel 20 degrees before top center the indicated mean effective pressure was 112 pounds per square inch, the fuel consumption 0.39 pounds per indicated horsepower per hour, and the mechanical efficiency 76 per cent. When the fuel was injected 31.5 degrees before top center, the indicated mean effective pressure was 132 pounds per square inch, the fuel consumption 0.33 pounds per indicated horsepower per hour, and the mechanical efficiency 81 per cent. The maximum cylinder pressures for the last-quoted performance were excessive and not permissible in a service engine.

Starting tests, made when the engine was cold, show that, starting from rest, only one revolution is necessary to obtain invariable starting with compression pressures of 420 pounds per square inch.

The engine idles continuously without load at 150 revolutions per minute, and at lower speeds until the inertia of the rotating parts fail to carry the piston through the compression stroke.

Two cylinder heads have been designed and are being constructed for use with the Universal test engine, in which special provisions have been made for varying the compression ratio, testing various types of injection valves, and investigating the effects of various kinds and degrees of turbulence.

The design of a piston for high-speed oil engine operation, incorporating fundamental methods for minimizing mechanical and thermal distortion and friction, chiefly by small, pressure-lubricated bearing surfaces and special autoseal piston rings, is practically completed.

A complete analysis of the cycle efficiencies that may be obtained in practice for various combinations of compression ratio, maximum cylinder pressure, and point of fuel cut-off has been undertaken. A considerable amount of test data, taken with the Universal test engine, has been used to establish approximate pressures, temperatures, and efficiencies for use in this investigation.

Fuel injection pumps and valves.—Further investigations on the performance of an accentric-operated injection pump have been made for various speeds, pump adjustments, injection valve opening pressures, and maximum injection pressures. This work has been done with the special bench testing equipment, by means of which the effects of the several variables in an injection system on the lag of the appearance of the spray behind the pump cycle, the duration of injection, the weight of fuel discharged per cycle, and the maximum injection pressure have been determined. A critical point in the lag of the spray, at which the first part of the injection changed from that caused by a pressure wave to that caused by normal pressure rise in the system, was found when investigating the effects of the opening pressure of an injection valve over a range from 600 pounds per square inch to 5,000 pounds per square inch. The information obtained has been used in connection with engine tests with the same injection apparatus.

The fuel-injection bench testing equipment has been equipped with a light-tight chamber fitted with a small blower to remove oil vapor, and an Elverson oscilloscope. This apparatus has been used to observe the start, development, and cut-off of fuel sprays under operating conditions, and has aided in obtaining a knowledge of the action of different injection values.

A new type of automatic injection valve, having only four parts and constructed without springs or sliding parts, has been developed for use with disk or conical shaped combustion chambers. The valve preheats the fuel and produces highly atomized sprays. The seats are constructed for continuous operation at temperatures up to 2,000° F. The performance reported for the Universal test engine was obtained for a small amount of fuel preheating with this injection valve.

A design of a similar injection valve, involving several modifications and fitted with thermocouples for temperature measurements, has been undertaken.

An automatic spring-loaded stem injection valve has been altered to give highly atomized fuel sprays with relatively high penetration. The valve has a high opening pressure, with injection and fuel cut-off at pressures approximately of the same value as the opening pressure. The performance reported for the second bulb-type cylinder head was obtained with this injection valve.

An automatic diaphragm-type injection valve has been constructed, the design of which permits easy adjustment of the valve opening pressures, positive control of the maximum deflection of the moving parts, a wide variation in the stiffness of the diaphragm spring unit, and interchangeability and alteration of different types of valve stems and nozzles. This injection valve has been used in connection with several investigations on the characteristics of oil sprays in dense gases, carried on with the committee's spray photography apparatus.

Fuel spray characteristics.—Several investigations on the characteristics of fuel sprays have been completed during the past year. The work was carried out with the fuel-spray photography apparatus constructed and developed by the staff of the committee. This apparatus is constructed to permit determination of the performance of various types of mechanically operated and automatic injection valves for injection pressures up to 10,000 pounds per square inch and spray-chamber pressures up to 600 pounds per square inch. Records of the start, development, cut-off, and distribution of the fuel sprays are obtained by photographing them on a moving film at intervals of from 0.00025 to 0.0005 second during the period of injection. The spray photography apparatus has been described in previous reports of the committee.

An investigation was made of the hydraulic and design factors influencing and controlling the exact reproducibility of fuel sprays, and the phenomena of secondary discharges from automatic injection valves. The reproducibility was found to be controlled by the initial pressure in the injection valve and tube, and the secondary discharges by pressure waves produced by the rapid opening of the fuel cut-off valve, in connection with the dimensions of the various parts of the apparatus.

The effects of altering the spray-controlling parts of centrifugal injection valves on the characteristics of fuel sprays have been determined. The investigation also included studies of a noncentrifugal valve. For this work the angle of the helical fuel grooves that produced the rotation of the fuel jet was varied from 90 degrees, i. e., axial grooves, to 23 degrees; the ratio of the orifice area to the total cross-section area of the helical grooves was varied from 0.19 to 2.05; the ratio of the orifice length to the orifice diameter was varied from 0.20 to 2.50; and the location of the seat changed from a position before the helical grooves and orifice to a position between the helical grooves and the orifice. It was found that a considerable change in the characteristics of the sprays was caused by the first three variables. The results are for an injection pressure of 8,000 pounds per square inch and chamber pressures up to 600 pounds per square inch, and are given in terms of spray penetration, velocity, volume, cone angle, and effective distribution, i. e., ratio of spray volume to oil volume. The effects of the four variables investigated are too numerous and interdependent to be summarized in this report.

An investigation of the effects of fuel and spray-chamber gas density and viscosity on the characteristics of fuel sprays has been completed. A standardized injection valve and standardized injection and spray-chamber pressures were used. Gasoline, kerosene, Diesel engine fuel oil, and a furnace fuel oil were compared when injected into compressed air. Diesel engine fuel oil sprays were studied when injected into air, nitrogen, carbon dioxide, and helium at pressures ranging from atmospheric pressure up to 600 pounds per square inch. The results of major importance were the increase of penetration and decrease in spray cone-angle and distribution with increase in fuel density; the negligible effect of gas viscosity on the spray characteristics; and the fact that the density of the gases controlled the penetration and other characteristics of fuel sprays at room temperatures.

An investigation of the performance of several types of injection valves for various injection and spray chamber pressures and a wide range of related conditions is under way.

It has been decided to extend the present spray photography equipment to permit the study of the effects of air pressure, temperature, turbulence, and dilution with exhaust gases, upon the lag of autoignition, source of ignition, and combustion of atomized fuels for oil engines. Conditions comparable to those existing within engine cylinders will be sought, but the apparatus will be designed to permit the fundamental investigation of each variable over a wide range of conditions independently of the other variables. Active work on this project has been started.

Fuel vapor pressures.—The data obtained in the investigation of the vapor pressures of six fuels, various mixtures of three of the fuels, a lubricating oil, and water are being prepared for publication. Temperatures up to 900° F. and pressures up to 5,000 pounds per square inch were recorded. The results indicate the stability and instability of the liquids tested and give the temperatures required to force the rapid vaporization of the fuels in an engine cylinder.

SUPERCHARGING—*Adaptability of supercharged air-cooled engines to flight conditions.*—Further study has been made of the adaptability of air-cooled engines to supercharging, using a Wright J–4A engine and a Roots type supercharger in a UO–1 airplane, in which the amount of supercharging was increased above that previously employed; that is, the supercharger capacity was increased to enable the maintenance of full supercharging to 28,000 feet, as compared to 18,000 feet, in order to determine the possibilities of utilizing the extra amount of supercharging with this type of engine. During this investigation considerable engine trouble was experienced from preignition caused by overheated spark plugs, the bronze bushings of which had become loosened in service, causing poor thermal conductivity and consequently poor spark-plug cooling. Extremely high cylinder temperatures accompanied this preignition condition both in flight and when operating at full throttle without supercharging on the ground. After the cylinders were fitted with new bushings this trouble was partially remedied, and several flights to 27,000 feet were made using varying amounts of benzol in the fuel mixture. In these flights the climb performance to 18,000 feet obtained with the lesser amount of supercharging was duplicated, but above that altitude cylinder temperatures increased somewhat above the maximum of 530° F. observed previously and, as no air cooler was employed, carburetor air temperatures increased from 160° to 200° F. Under these conditions there was a loss in engine speed and very little, if any, improvement, in the climb performance above 18,000 feet; in fact, the climb performance in some cases was considerably inferior.

From these results it was concluded that the extra amount of supercharging was not practical with this engine, owing in part to insufficient cylinder cooling capacity, poor spark plug cooling, and existence of high carburetor air temperatures, all of which combined to minimize the improvement in airplane performance to be expected from the additional supercharging. These conclusions must be qualified, however, as an engine having better spark-plug cooling might very probably have given better results.

In view of the success met with in employing the lesser amount of supercharging with the Wright J type air-cooled engines, a supercharger of more suitable proportions for use with 200 horsepower engines has been constructed. This supercharger has a displacement of 0.19 cubic foot per revolution and is designed to operate at rotor speeds from two to three times crankshaft speed. Tests of this supercharger in the laboratory have indicated a reduction of only 8 to 10 per cent in volumetric efficiency at a rotor speed of 6,000 revolutions per minute.

Characteristics of Roots superchargers.—Three superchargers suitable for use with 400 horsepower engines, having 25 per cent less displacement than the original supercharger designed for the Liberty engine and being geared to operate at increased rotor speeds to offset the reduced displacement, have been constructed. One of these machines has been tested in the laboratory to determine the characteristics of this type supercharger at the higher rotor speeds. It was found that the volumetric efficiencies at a rotor speed of 5,300 revolutions per minute ranged from 95 per cent with no compression to 90 per cent with 12 inches of mercury pressure difference across the rotors. At this speed and pressure difference, about 63 horsepower was required to handle 1.4 pounds of air per second with 75° F. intake-air temperature. The power required for a given air weight and pressure difference was slightly higher than for the original supercharger, owing to the increase in rotor speed necessary. The power required to drive the supercharger with free intake and discharge was 7.5 horsepower at 5,300 revolutions per minute, the power at lower speeds following an approximate cubic relation. At a given speed the power was proportional to the pressure difference, but at a given pressure difference the power increased with speed somewhat more rapidly than proportionally.

These tests have shown that the higher rotor speeds are practicable, thus enabling the advantages of reduction in size of the unit to be realized.

The effect of supercharger capacity on airplane performance.—One of the new type Roots superchargers has been mounted in a modified DH–4 airplane and flight tests started to determine the effect on airplane and engine performance of varying the supercharger capacity by changing the rotor speed. The present supercharger is geared to operate at 1.97 times crankshaft speed, giving a critical altitude of about 13,000 feet; and it is planned to use three additional drive ratios, giving critical altitudes from 9,000 feet to 22,000 feet. Engine power will be obtained by using calibrated propellers.

Problems incidental to supercharging.—In connection with the problem of determining directly the altitude performance of supercharged engines, and thus establishing the relation between theoretical and actual performance, the full-scale propellers used in supercharger research with the DH–4 airplane are being calibrated in flight to obtain power and torque coefficients. A Bendemann hub type dynamometer used in obtaining these calibrations has proved suitable for this purpose. A report on the results obtained during preliminary flight tests of this dynamometer apparatus has been issued.

An investigation is also being undertaken to determine the relative specific fuel consumption of normal and supercharged engines in flight. In this connection, fuel-flow meters suitable for flight use are being investigated, but so far no instrument suitable in all respects has been developed.

BUREAU OF STANDARDS

Supercharging of aircraft engines.—The purpose of this investigation has been to determine the maximum improvement in engine performance to be expected as a result of supercharging. By means of the altitude-laboratory equipment it was possible to maintain sea-level pressure at the entrance to the carburetor and the pressure of the desired altitude at the exhaust ports. During the past year a Liberty–12 engine has been tested over a wide range of temperatures and pressures, and the results of this test, together with results of a previously made test of a Curtiss D–12 engine, are to be incorporated in a report to be published by the National Advisory Committee for Aeronautics.

Friction of aviation engines.—A report of this investigation has been completed. It discusses the influence of certain factors upon engine friction, among which are temperature of the air entering the engine, atmospheric pressure, throttle opening, engine speed, jacket-water temperature, compression ratio, and piston design.

Phenomena of combustion.—This investigation has been in progress several years. It is primarily a study of the factors which are of fundamental importance in governing the rates of explosive gaseous reactions and the nature of the physical and chemical phenomena involved, the ultimate object being more complete data on the explosive gas reaction in engine cylinders. During the year velocities of the carbon-monoxide-oxygen reaction have been measured for pressures of 1,400, 1,520, 1,700, and 1,900 millimeters of mercury. Several hundred measurements have also been made for pressures less than atmospheric.

Tests of fuel volatility.—Atmospheric distillations are at present generally used as the basis for judging the volatility characteristics of fuels. The results of such distillations are not, however, readily translatable into expected performance in the engine nor do they permit of direct quantitative comparison of fuels. For these reasons other methods of measuring fuel volatility have been investigated and a method which gives promise of being very useful has been developed. This method consists essentially of an atmospheric distillation in the presence of air.

Fuels for high-compression engines.—A considerable number of cracked gasolines have been tested in the single-cylinder engine during the past year. These gasolines in general are superior to straight-run products as regards antiknock characteristics. In that respect, therefore, they are particularly adapted for use in high-compression engines.

Investigation of bearing friction.—By means of a simple friction machine, comparisons have been made between the friction of a bearing when a light mineral oil is used and when the same oil containing 1 per cent of diatomaceous earth is used. The results suggest the desirability of high viscosity from the standpoint of reducing wear, but the work has not been carried far enough to show whether or not, in a given type of equipment, the advantages of a high viscosity would outweigh the added difficulty of supplying an adequate amount of lubricant to the bearing surface and the increase in friction due to the higher viscosity.

Measurements of "break-away" torque.—A study has been made of the relation between oil viscosity and the torque required to start an engine in rotation. Results indicate that while the viscosity of the oil does have a pronounced effect upon the power required to rotate the engine at speeds of 100 revolutions per minute and higher, it does not affect appreciably the power required to start the engine nor to rotate it very slowly. In the light of these results it appears probable that when an engine starts or is operating very slowly practically all of the oil is squeezed out from between the rubbing surfaces and lubrication is dependent upon the so-called "oiliness" film.

Antifreezing solutions.—The past year has witnessed unusual activity in the development of antifreezing solutions for the cooling systems of internal-combustion engines. The freezing point of many of these solutions has been measured by the Bureau of Standards and their corrosive properties investigated.

NEW ENGINE TYPES

The Army Air Corps has discontinued for the present the development of the Almen engine upon which it has been working for some time. While this engine has interesting possibilities as compared with other water-cooled types, it suffers by comparison with the new air-cooled engines when power-plant weight is taken into consideration. The cam engine on which the preliminary work was done by the Army Air Corps has now been taken over by the Fairchild company and is being flight tested and further developed. It appears to have interesting possibilities from the standpoint of cheapness of construction. The Attendu heavy-oil engine under development by the Bureau of Aeronautics has shown sufficient promise to warrant the consideration of the next step in the development of such an engine, namely, a multicylinder engine for service use. It is expected that by utilizing the interesting results of the fundamental research conducted by the Langley Memorial Aeronautical Laboratory of this committee, substantial progress can be made in heavy-oil engines for aircraft.

In the water-cooled engine field but one new type of engine has been initiated. The Army Air Corps and the Curtiss Aeroplane & Motor Co. have brought out the new Curtiss V–1550, an engine incorporating the excellent features of its predecessors, the Curtiss D–12 and V–1400 engines. The new engine is conservatively rated at 500 horsepower at 2,100 revolutions per minute, and is being built with direct and with geared drive. The gears are of Curtiss design and construction and have successfully passed their endurance tests. The two Packard engines, the 1,500 and 2,500 cubic-inch models, have gone into quantity production for the Navy. Through refinements and improvements they have been advanced from the 1A–1500 and 1A–2500 to the 3A models of both engines. The Navy is using the 1,500-cubic-inch engine as direct drive, inverted, and geared types, the direct-drive engine being used in the aircraft-carrier pursuit or fighting type airplanes, the inverted engines in the aircraft-carrier and battleship amphibian spotting-type airplanes, and the geared engines in the long-range patrol airplanes of the PN–10 type. The Army Air Corps is using the Packard 2,500-cubic-inch geared engine in a number of single-engined bombers. The Navy has on order 150 Packard 3A–2500 direct-drive engines for its aircraft-carrier type of bomber.

The most striking development of the year is the advance made in air-cooled engine types. The Wright model J–4 has advanced to the J–5 type, of which type the Navy has ordered over 300. This engine includes among its improvements a greatly improved cylinder construction, fully inclosed valve gear, the new Eclipse concentric-impulse or flywheel starter, and a three-barreled carburetor. The new cylinder construction permits full throttle operation at fuel consumptions 10 per cent less than that usually obtained in engines using water-cooled cylinders. The J–5 engine has been supercharged at sea level to an unusually high mean effective pressure. Its cooling is excellent. The Wright P–2 radial air-cooled engine which has been under development for some time has been superseded by newer types which are far more promising.

Two new types of radial air-cooled engines are being developed for the Navy by the Pratt & Whitney Aircraft Co. The first of these engines, the "Wasp," has a displacement a little over 1,300 cubic inches. On this capacity it develops a normal horsepower of 425 on a dry weight of 650 pounds, including the propeller hub but excluding the Eclipse starter. This engine, the development of which began with the organization of the Pratt & Whitney Co. August 1, 1925, has proved most successful. The "Wasp" has been thoroughly flight-tested in various types of fighter airplanes and has been adopted by the Navy as the standard type engine for pursuit or fighting airplanes. A contract has recently been let for 200 of these engines, which are required to meet the Navy's building program for this year.

Simultaneously with this development, the Pratt & Whitney Co. has been developing a larger radial air-cooled engine for the Navy, to be known as the "Hornet." The engine conforms in general to the "Wasp" design but has a displacement of 1,690 cubic inches and is expected to develop 500 horsepower at 1,800 revolutions per minute. This engine is designed for use in heavy-duty types of aircraft, such as scouting, bombing, and torpedo seaplanes, either single or twin engined.

In competition with the "Hornet" the Wright Aeronautical Corporation is building a large radial air-cooled engine (the R–1750 "Cyclone"), which is being tested. This engine also is designed to meet the Navy's requirements for a heavy-duty engine. It incorporates all the results of the Wright Co.'s previous wide experience in the radial air-cooled engine field. From these two engines the Navy expects to be able to choose an excellent power plant for its aircraft-carrier bombers.

The Army Air Corps has continued the development of its air-cooled Liberty with a view to conducting flight tests and determining the possibilities of the V-type air-cooled engine. The results to date have been encouraging. The success of both the radial and V type air-cooled engines in pursuit or fighting types of airplanes is one of the striking events of the year. At present the trend in practically all new types of aircraft engines is away from water cooling and toward air cooling.

REPORT OF COMMITTEE ON MATERIALS FOR AIRCRAFT

ORGANIZATION

The present organization of the committee on materials for aircraft is as follows:

Dr. George K. Burgess, Bureau of Standards, chairman.
H. L. Whittemore, Bureau of Standards, vice chairman and acting secretary.
S. K. Colby, American Magnesium Corporation.
Henry A. Gardner, Institute of Paint and Varnish Research.
Dr. H. W. Gillett, Bureau of Standards.
Prof. George B. Haven, Massachusetts Institute of Technology.
Zay Jeffries, Aluminum Co. of America.
J. B. Johnson, matériel division, Army Air Corps, McCook Field.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Capt. H. C. Richardson, United States Navy.
G. W. Trayer, Forest Products Laboratory, Forest Service.
Starr Truscott, National Advisory Committee for Aeronautics.
Hon. Edward P. Warner, Assistant Secretary of the Navy for Aeronautics.

FUNCTIONS

Following is a statement of the functions of the committee on materials for aircraft:

1. To aid in determining the problems relating to materials for aircraft to be solved experimentally by governmental and private agencies.

2. To endeavor to coordinate, by counsel and suggestion, the research and experimental work involved in the investigation of such problems.

3. To act as a medium for the interchange of information regarding investigations of materials for aircraft in progress or proposed.

4. To direct and conduct research and experiment on materials for aircraft in such laboratory or laboratories, either in whole or in part, as may be placed under its direction.

5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

The committee on materials for aircraft, through its personnel acting as a medium for the interchange of information regarding investigations on materials for aircraft, is enabled to keep in close touch with research in this field of aircraft development. Much of the research, especially in the development of light alloys, must necessarily be conducted by the manufacturers interested in the particular problems, and both the Aluminum Co. of America and the American Magnesium Corporation are represented on the committee. In order to cover effectively the large and varied field of research on materials for aircraft, three subcommittees have been formed, as follows:

Subcommittee on metals:
- Dr. H. W. Gillett, Bureau of Standards, chairman.
- Zay Jeffries, Aluminum Co. of America.
- J. B. Johnson, matériel division, Army Air Corps, McCook Field.
- George W. Lewis, National Advisory Committee for Aeronautics (ex officio member)
- Starr Truscott, National Advisory Committee for Aeronautics.
- H. L. Whittemore, Bureau of Standards.

Subcommittee on woods and glues:
- G. W. Trayer, Forest Products Laboratory, Forest Service, chairman.
- H. S. Betts, Forest Service.
- George W. Lewis (ex officio member).
- H. L. Whittemore, Bureau of Standards.

Subcommittee on coverings, dopes, and protective coatings:
- Henry A. Gardner, Institute of Paint and Varnish Research, chairman.
- Dr. W. Blum, Bureau of Standards.
- Warren E. Emley, Bureau of Standards.
- Prof. George B. Haven, Massachusetts Institute of Technology.
- Isadore M. Jacobsohn, Bureau of Standards.
- George W. Lewis (ex officio member).
- P. H. Walker, Bureau of Standards.
- E. R. Weaver, Bureau of Standards.

Most of the research in connection with the development of materials for aircraft is financed directly by the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, and the National Advisory Committee for Aeronautics.

The Bureau of Aeronautics and the matériel division of the Air Corps, in connection with the operation of tests in their own laboratories, apportion and finance research problems on materials for aircraft to the Bureau of Standards, the Forest Products Laboratory, and the Industrial Research Laboratories.

MEETINGS OF THE COMMITTEE

The committee held several meetings during the year. The corrosion of the light alloys having received considerable attention in both the technical and the lay press as a result of the loss of the *Shenandoah* and the subsequent investigations, this subject was discussed at each meeting. At a meeting held at the Langley Memorial Aeronautical Laboratory, Langley Field, Mr. J. A. Boyer, chief chemist of the American Magnesium Corporation, discussed the corrosion of magnesium and the magnesium aluminum alloys containing manganese in a most illuminating manner. This paper will be published by the committee as a technical report. After this meeting the committee inspected the laboratory and later visited the naval air station at Hampton Roads, Va. In the course of this visit an all-metal airplane about 6 years old, which had been exposed for three years, was inspected and samples of the parts of the structure were taken. Much interest was shown in the all-metal floats of certain seaplanes which had just returned from the Tropics. The personnel of the station discussed the behavior of these floats in considerable detail.

SUBSTITUTE FOR SILK PARACHUTE CLOTH

The general increase in the use of parachutes makes it desirable to develop American-made substitutes for the silk cloth used in their manufacture. At present this is practically all imported as cloth. Very good success has been obtained in the development of American-woven silk cloths to be substituted for the imported.

The committee has also had under way for some time an investigation intended to develop a cloth acceptable for use in the manufacture of parachutes which might be made in this country from materials produced here. After preliminary investigation the problem has resolved itself into the finding of a method of treating cotton yarns which will impart to these yarns the added strength and elasticity required to make them equal silk yarns.

A very careful study has been made of the physical properties of silk parachute cloth and its constituent yarns and these have been compared with cotton yarns. In order to produce the necessary increase in the strength and elasticity it has been found necessary to subject the yarns from which the cloth is to be woven first to a process of mercerization and then to a coating with a special dope. It has been demonstrated that it is possible to increase the strength of cotton yarns very considerably by the special dope, and this phase of the problem is fairly well along. However, the stretch is little affected by the doping, and the treatment which promises most improvement here is mercerization.

A very careful study has been given to the general subject of mercerization, especially as applied to fine cotton yarns, and processes which appear to give the desired results have been developed.

The question of the origin of the yarns has also been studied and yarns made from Egyptian (probably Sakellaridis), Indian Sea Island, Egyptian, and Sea Island cottons have been experimented with. Incidentally this work has required a lengthy study of the effect of twist in the yarns on their properties.

So far the work has been done on a laboratory scale and it has proved difficult to produce any large quantities of treated yarns having generally the same characteristics. However, several pieces of experimental cloth have been woven to determine whether the woven cloth would develop the properties expected from the yarns. In order to economize on treated yarn, the cloths were woven using a warp of normal yarn and filling of treated yarn. When tested for tensile strength, stretch, and resistance to tear, these cloths have given fairly satisfactory results, but not what was anticipated. Certain difficulties due to the scale on which the work is being carried on must be overcome, probably by working on a somewhat enlarged scale.

Although the progress is not as great as was hoped for the past year it has been material, and in view of the information which has been obtained it is believed it will not be long before an acceptable substitute can be supplied to replace the imported silk parachute cloth.

SUBCOMMITTEE ON METALS

Intercrystalline embrittlement of duralumin.—During the past year this subcommittee has worked on the program for investigating intercrystalline embrittlement of duralumin, which was approved by the committee on materials for aircraft last year.

Sheet duralumin had previously been found to be subject to a peculiar deterioration resulting from corrosion. Without any marked surface evidence of the change, the metal may become very brittle as a result of the weakening of the intercrystalline "bonds" by corrosion. The change begins at the surface and gradually penetrates inward.

Considerable progress on this investigation has been made and it is believed that satisfactory solutions for many phases of the problem are in sight. Much time necessarily has been spent, however, on examination of materials from the U. S. S. *Shenandoah* and U. S. S. *Los Angeles*.

This work has considerably delayed the completion of the program on embrittlement. This examination of different material from the airships which had seen considerable service showed that both the lattice and the channel sections were more susceptible to corrosion if the metal had been worked after heat treatment.

An encouraging fact which should not be overlooked is that almost all the duralumin which has been used for airship construction in this country has given satisfactory service until the airship was taken out of commission. It is realized, however, that the design for future airships may impose conditions for which any corrosion of the duralumin might reduce the structural strength of the airship. This is particularly true if the duralumin is to be used in very thin sections. Slight corrosion, which in more massive sections would be of little importance, in these very thin sheets would be very dangerous.

The purpose of the investigation has therefore been twofold:

First. To study those factors in duralumin (composition, heat treatment, mechanical treatment, etc.) which are favorable to this type of corrosion with the aim of making the alloy more resistant to corrosive attack.

Second. To study means for protecting or modifying the surface of duralumin.

Dependable methods of producing intercrystalline corrosion have been developed. Tension test bars are used as specimens throughout and are pulled in tension after a definite exposure to corrosive attack by a solution of sodium chloride and hydrogen peroxide. Materials from several different sources have been used in the investigation. These have been tested plain and coated in a variety of ways.

All the duralumins examined were corroded by the method used. Usually this produced a combination of pitting and intercrystalline penetration. Proper heat treatment appeared to reduce the severity of the attack but cold working after heat treatment increased it. However, it seems improbable that complete immunity to intercrystalline attack can be had in the Cu-Mg-Si type of alloy, which gives the highest physical properties, since the present indications are that susceptibility to attack is connected with the presence of copper.

Although laboratory tests can not truly reproduce service conditions, it is believed that protection by spraying with pure aluminum, followed by heat treatment, and the coating with bitumastic enamel are probably the two surest methods. Other methods, of varying qualities, are, however, available.

Exposure panels protected by various methods have been paralleled with tension bars similarly coated. These will be tested at intervals to determine the change in physical properties with exposure.

If the laboratory tests can be taken as criteria of service, properly protected duralumin is a thoroughly dependable material of construction.

From its work so far the committee is convinced that—

(1) Although the corrosion of duralumin is a serious matter, especially because the attack may be almost completely hidden, it is not more serious than the corrosion of ferrous metals.

(2) The corrosion of duralumin can be prevented for all practical purposes.

Structures for airships.—Tests of girders duplicating those used in the *Shenandoah*—made while that airship was under construction—showed that the strength of such girders was determined by the elastic properties of the channels and the type of restraint offered by the lattices. The principal elastic constants of the channels are their flexural stiffnesses (moments of inertia × Young's modulus) in the directions of the two principal axes of inertia and their torsional stiffness (torsion constant × shear modulus).

An investigation is being conducted to determine by tests the relative importance of these three constants in determining the strength of the girders. For this purpose it has been necessary to study accurately and in detail the deformation of the channels in the girders under compressive loads, first unconstrained and then with outside constraints applied to prevent particular types of deformation. This has been done in the large Emery testing machine at the Bureau of Standards, using a technique especially developed for the purpose of securing the proper loading conditions and accurate determination of the deformations.

Because of the large amount of testing made necessary by the work in connection with the investigation of the loss of the *Shenandoah*, not as much progress has been made as was anticipated. However, complete tests have been made on two girders differing radically in their lattice arrangement, a special girder with opposite latticing and a standard girder with spiral latticing.

These tests included runs with no restraint, restraint of the twist of 1, 2, and 3 chord members, respectively, and restraint of spread of the channel lips. Over 14,000 individual measurements were made.

The characteristic wavy flexure of these girders was shown to be almost wholly a twist of the channel section. Restraining the twist of the chord members without in any way restraining the lateral deflection or spread of the flanges increased the carrying capacity of the girders by over 40 per cent. The torsional stiffness of the channels is then the major controlling factor in determining the strength of these girders.

The strength of this type of girder can be materially increased, without increase in weight, only by increasing the resistance of their chord members to twist, either (*a*) by increasing their torsional stiffness, or (*b*) by altering the manner of their lattice support. Restraining the spread of the outstanding flanges or increasing the moments of inertia of the section without increasing the torsional stiffness will not appreciably increase the strength.

It is planned to see if these results will be confirmed by repeating the tests upon a sufficiently wide range of girders to establish the range of application of these conclusions. The completion of the tests promise to make it possible—

(1) To determine the strength of a full-length latticed girder of the Zeppelin type from tests on short sections;

(2) To predict the strength of a girder of this type from tests on the chord members alone; and

(3) To predict the strength of girders of this type from a knowledge of the three elastic constants of the chord members and the dimensions of the girders alone.

The full or even the partial working out of these results in a definite form would provide the basis for a rational (as contrasted with a purely empirical) development of improved designs which would furnish stronger girders of equal weight or lighter girders of equal strength than are at present possible.

New experimental chord-member sections have been fabricated. These are designed to eliminate the eccentric application of the lattice restraints which tests have shown contribute to the torsional failure of the girders. It is planned to test these sections to see how far they accomplish the desired result.

As a result of a careful and extended investigation of wreckage from the *Shenandoah*, made for the court of inquiry on the loss of that airship, the conclusion was drawn, "No single specimen was found which had deteriorated sufficiently to lower the resistance of the structure of the ship to static or aerodynamic loads, nor was any evidence found that fatigue failure had contributed to the wreck of the ship." The basis for this statement lay in the fact that the original tests of girders made for the Bureau of Aeronautics during the construction of the airship had shown that "they would fail by flexure within the elastic limits of the material without producing tensile stresses in any case of more than 36,050 lbs./sq. in. as found by tests."

It was, however, thought desirable to confirm these conclusions by tests of full-sized girders comparable with the tests made while the airship was building. Two 5-meter girders were salvaged from the wreckage in which only small twisting of the channels had been produced by the crash, although several of the lattices were badly bent and broken. These were reconditioned in the following manner. The broken and damaged lattices were removed, the channels were straightened, and the lattices then replaced by other undamaged lattices salvaged from the wreck. There was therefore no new material in the girders tested, as it all came from the *Shenandoah* wreckage.

Test fixtures taken from the original girder tests were used and the tests repeated, reproducing the conditions and methods of the original tests with one exception. Since there were only two girders, it was desired to use each girder for both a column test and a beam test. Consequently, steps were taken to prevent the complete collapse of the girder, when tested as a column, after the maximum load was passed. Limiting stops were placed so that the increase in lateral deflection after the column became unstable could not exceed a few tenths of an inch.

In the column tests the columns were loaded to beyond the maximum axial load. They then suddenly became unstable and came to rest against the stops, producing some deformation of the channels and destroying one or two lattices. They were reconditioned as before and again tested, this time as beams and to destruction, under the same conditions as in the original tests.

The test loads carried, both as columns and as beams, were as high as the corresponding girders had carried in the original tests, thus confirming fully the conclusions quoted.

High-speed fatigue testing.—A decision was reached to adopt the type of high-speed fatigue testing machine in which the specimen is loaded by means of compressed air. The specimen is set into flexural vibration which produces pure bending without shear. After the construction of a single experimental machine a battery of machines has been completed and these are now available for operation. For the present all the test specimens used are made of duralumin. However, material for magnesium test specimens is now available and it is planned to extend the series to steel specimens if this proves feasible.

The results so far obtained appear to be comparable very closely with those obtained from the mechanical fatigue machines which were developed for determining the fatigue resistance of metal used in the *Shenandoah*. A tendency to develop lower fatigue values has been traced to the existence of corrosion in some sheet material which had been on hand for a considerable period.

SUBCOMMITTEE ON WOODS AND GLUES

The Forest Products Laboratory of the Department of Agriculture conducts practically all the investigations on the application of woods and glues to aircraft construction. These investigations are undertaken at the request of the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, or the National Advisory Committee for Aeronautics. Some of the more important investigations now in progress are outlined below.

Continuous beams.—From a previous study of the stress distribution in continuous beams under transverse load only, there were obtained simplified methods of calculation which led to greater accuracy in design. The theoretical foundations for these methods were checked by tests.

The methods of calculation developed for transverse loading seemed to apply quite well, with slight modifications, to continuous beams under combined transverse and axial loadings. However, the Bureau of Aeronautics wished additional tests to corroborate this idea. Accordingly, 32 **I** and box beams of conventional type were tested for this purpose. The results demonstrated that essentially the same principles were involved as in the previous work and justified the extension of the method.

Design of plywood webs for box beams.—Until quite recently practically all plywood for web material of box beams was made in three plies. Now two-ply material is commonly used for such purposes. The purpose of this study was to compare the two types and to determine working stresses for both. It was found that when similarly constructed, two-ply web material was equally as efficient as three-ply. Allowable shear stresses for the two types were set up for conventional box beams without diaphragms and for beams with various diaphragm spacings.

Bearing strength of bolts in wood.—This is the subject of a series of investigations on the strength of bolted fastenings. The first report of the series dealt with solid bolts and a condition of loading where the pull on the bolt was parallel to the grain of the wood, and the second dealt with hollow bolts under the same conditions of loading. The third report covers the case where the pull is at an angle to the grain and in the plane determined by the grain of the wood and the axis of the bolt.

The analysis of the test data of the third report shows that—

(1) The end pull on the bolt must be taken care of by ample washers or plates.

(2) The line of action of the pull must meet the surface of the timber between the bolts or within the polygon joining the bolts.

(3) Under the condition of loading of this report the strength of a joint is dependent upon the component of the force parallel to the grain of the wood and may be calculated from the curves of the former reports by using the component of the stress parallel to the grain of the wood.

Determination of acceptance-test values.—In the inspection of wood for airplanes, the need has been felt for a simple and expeditious mechanical test which could be applied to each piece to determine its acceptability. To meet this need the Forest Products Laboratory toughness-testing machine was developed.

Studies were made to obtain data enabling the use of this machine for the inspection and selection of suitable airplane woods, and were completed on white oak, black walnut, yellow birch, white ash, and Sitka spruce.

This year data for Douglas fir (coast type) have been added to the list. It is now possible by the use of this machine to inspect and select woods of high quality of the six species for which minimum values have been established.

Seasoning practice at naval aircraft establishments and contractors' plants.—At the request of the Bureau of Aeronautics, Navy Department, an inspection was made of the lumber-seasoning practice at a number of naval aircraft establishments and contractors' plants. Individual inspection reports on the various plants visited and a final summary and report were submitted. Many specific recommendations and suggestions were made as well as a number of general recommendations.

Preparation of publication on gluing.—A manuscript on gluing woods for aircraft purposes has been prepared and is now ready for editing for publication. It is based on the results of various investigations on glues and gluing and, in the light of these and other data, outlines methods and procedure with particular reference to aircraft requirements. It deals specifically with glues for aircraft, preparation of glues for use, preparation of wood for gluing, application of glue to the wood, pressing, drying, and conditioning glued stock, and other subjects.

Testing of commercial water-resistant glues.—Fourteen different brands of commercial water-resistant glues were tested by the block and plywood-joint test methods and observations were made as to their mixing characteristics, working life, and hardness. Tests were also made on samples of casein glues in stock since 1918.

The casein glues tested were not extraordinary, although some of them should be classed among the better grades of this class of adhesives.

Hot-press glues made in England tested high in water resistance, although equally high results have been obtained with the cold-press blood glue formula developed by the Forest Products Laboratory.

The soya-bean glue, which came into use within the past few years, has been improved until it is equal in water resistance to some of the medium grades of casein glues. In dry strength generally speaking, it is still somewhat below the casein glues.

Manufacture of casein water-resistant plywood.—As a result of this investigation it has been concluded that the requirements for grade A plywood are so severe in some respects that they can not at present be complied with consistently by plywood glued with casein glue. It was found further that plywood test values, obtained under present testing methods, are variable for different combinations of ply thicknesses, and curves expressing the relation of face and core thicknesses to test values have been worked out. Based upon this relation of test values to ply thicknesses, it has been shown that a specification value suited to the easy combinations, such as allowed in one-sixteenth and three thirty-seconds inch panels, may not be just for difficult combinations as required at present in one-eighth and three-sixteenths inch panels. The working out of this relationship has explained why it has been possible to meet the requirements of grade A plywood in some cases and not in others with the same care gluing.

Development of water-resistant glues.—The work on the development of water-resistant glues has resulted in a formula for making animal glue water resistant through the addition of paraformaldehyde. In the past the drawback to mixtures of animal glue and formaldehyde has been their quick setting, which has made their use impractical in commercial operations. By the addition of a small amount of acid, the working life of an animal-glue-paraformaldehyde mixture has been extended to several hours. Oxalic acid was one of the most effective acids used, yielding a glue of a suitable working life and at the same time of high water resistance. The treated animal glue compares well in water resistance to the better casein glues and there is a possibility that it may be more durable under prolonged exposure to damp conditions.

SUBCOMMITTEE ON COVERINGS, DOPES, AND PROTECTIVE COATINGS

Gas-cell fabrics.—Work on the further development of experimental gas-cell fabrics has gradually eliminated many of the compounds which were considered to afford possible solutions of this problem, and has led to concentration on two types. The one uses sheets of commercial cellophane as a substitute for the sheets of goldbeater's skins and has been developed sufficiently to enable the construction of a full-sized gas cell. The fabric of this cell has been subjected to unusually severe conditions of handling during the period of manufacture and to the further unfortunate circumstance that it was necessary to stop all work on it for a period of some months while more urgent repairs to other gas cells were being carried on by the naval aircraft factory. In spite of these difficulties, the fabric first made appears to be in splendid condition. An experiment intended to improve the fabric by impregnation of the cellophane of certain areas with glycerine resulted unfortunately, as the glycerine caused the material to take up water and the cellophane separated from the foundation fabric. These defects will be remedied by the use of cellophane in which the glycerine is compounded initially. It is anticipated that this cell will be placed in the *Los Angeles* for test in a very short time.

The other type of fabric is believed to contain even more promise than the cellophane fabric. In this case the gas-containing compound is spread on the foundation fabric instead of being cemented on as in the case of goldbeater's skin fabric or the cellophane fabric. An experimental production order for about 1,500 yards of this type of material has been placed and preliminary results indicate that the shop production will be, if anything, superior to the laboratory production and that the quality of the resulting fabric will correspond. As this fabric has shown a permeability much lower than that of goldbeater's skin fabric and weighs even less, it is being watched most carefully.

Although other types of fabric are being examined, the great promise offered by the two types which have just been described has led to a slowing down in the search for new types and a concentration of effort on the development of the two which seem to have the most promise. Most of the work connected with the experimental study of the fabrics has been done at the Bureau of Standards. The construction of the experimental gas cell has been done at the Naval Aircraft Factory. If the resultsf rom the experimental production order for the second type of fabric prove to be as good as anticipated, there will be a similar experimental gas cell constructed of that fabric.

Coatings for duralumin to prevent corrosion.—Experiments with the anodic treatment have continued. In contrast to the good results reported by the British, this process has not been as satisfactory in this country as was expected. It has been found desirable to paint or varnish over the anodic coating in order to improve the protection.

Paint and varnish of conventional type have been found to be of short life as a protective coating, particularly in salt water. Apparently the water penetrates the paint and the coating quickly separates from the metal.

A process has been developed by means of which a thin layer of gum rubber can be built up on a duralumin surface with the adhesion between the rubber and the metal of a very high order. This protection has been applied to a seaplane float and also to a number of test samples. The information received so far indicates that the protection is very good. Bituminous paints still remain the most certain protection where they are not exposed to sunlight. When exposed to sunlight they break down and dust off unless given a light color by means of some added pigment.

The application of a thin coat of pure aluminum by means of the metal-spray gun seems to give a very high degree of protection. This may be combined with additional painting or coating, as may be desired. On account of its recent introduction the life of this type of coating can be judged only by its behavior in accelerated corrosion tests. It will probably be necessary to await the results of a series of exposure tests which are now under way at Hampton Roads on about 250 specimens before definite conclusions can be reached. In these exposure tests all manner of coatings are being tested, both qualitatively and quantitatively. The quantitative test is obtained by applying the coatings under examination to standard test bars and breaking these bars at intervals in a tension machine. The reductions in tensile strength and elongation afford a very accurate measure of the degree to which the protective coating has failed to do its work.

The introduction of the nitrocellulose lacquers for the protection of small types of metal fittings was attended by the difficulty that such lacquers were applied practically uniformly by spray. During the past year methods have been developed for the application of these lacquers by hand brush, thus making it possible to use them for the painting of small parts of airplanes. The quick drying of these lacquers—from 5 to 20 minutes—makes them highly desirable under some conditions.

Airplane dopes and paints.—A rather comprehensive study was made during the past year of the durability obtained from various schemes of airplane doping and varnishing. This includes a study of the use of cellulose acetate and cellulose nitrate dopes and other schemes for airplane fabric surfaces. The tests were made in Washington at the Institute of Paint and Varnish Research, and at the United States naval air station, Pensacola, Fla. The effects of various colors and plasticising agents were studied.

The weight of the fabric, its tensile strength and tautness were determined both before and after exposure. The tautness tests were made both by striking the dope panels and by an apparatus devised by Barnaby and Freymoyer. The two methods checked up very well. Very comprehensive tables of results were obtained and it was finally recommended that one type of dope, namely, nitrate dope, should be used exclusively for airplane surfaces and that it should be pigmented at the time of application by the addition of approximately 10 per cent of aluminum powder. As a result of the adoption of the standard recommended from these tests, one type of dope can be carried in stock with a small amount of aluminum powder and used for all doping. The use of clear varnish over the doped surfaces for the purpose of keeping the fabric clean was also suggested.

PART IV

TECHNICAL PUBLICATIONS OF THE COMMITTEE

During the past year the committee added a new series of publications known as Aircraft Circulars, making a total of four series of technical publications issued regularly by the committee. Only one series is printed, that known as Technical Reports, the other three series being mimeographed.

On recommendation of the committee on publications and intelligence, the National Advisory Committee for Aeronautics has authorized the printing of 24 Technical Reports during the past year covering a wide range of subjects on which research had been conducted under the cognizance of the various subcommittees, each report having been approved by the subcommittee concerned and recommended to the executive committee for publication. The Technical Reports represent fundamental research in aeronautics carried on in different laboratories in this country, including the Langley Memorial Aeronautical Laboratory, the aerodynamical laboratory at the Washington Navy Yard, the Bureau of Standards, the Weather Bureau, Stanford University, and the Massachusetts Institute of Technology.

To make available immediately technical information on experimental and research problems, and to present the results of small research investigations and the results of studies of specific detail problems which form parts of long investigations, the committee has during the past year issued in mimeograph form 20 Technical Notes.

The third series of publications, known as Technical Memorandums, contain translations and reproductions of important aeronautical articles of a miscellaneous character. A total of 50 Technical Memorandums were issued during the past year.

The new series, known as Aircraft Circulars, contain translations or reproductions of articles descriptive of types of aircraft. This series was inaugurated in May, 1926, and up to the end of September 16 circulars were issued.

Summaries of the 24 Technical Reports and lists of the Technical Notes, Technical Memorandums, and Aircraft Circulars issued during the past year follow.

SUMMARIES OF TECHNICAL REPORTS

The first annual report of the National Advisory Committee for Aeronautics contained Technical Reports Nos. 1 to 7; the second annual report, Nos. 8 to 12; the third annual report, Nos. 13 to 23; the fourth annual report, Nos. 24 to 50; the fifth annual report, Nos. 51 to 82; the sixth annual report, Nos. 83 to 110; the seventh annual report, Nos. 111 to 132; the eighth annual report, Nos. 133 to 158; the ninth annual report, Nos. 159 to 185; the tenth annual report, Nos. 186 to 209; the eleventh annual report, Nos. 210 to 232; and since the preparation of the eleventh annual report the committee has authorized the publication of the following Technical Reports, Nos. 233 to 256.

Report No. 233, entitled "The Aerodynamic Characteristics of Seven Frequently Used Wing Sections at Full Reynolds Number," by Max M. Munk and Elton W. Miller, National Advisory Committee for Aeronautics.—This report contains the aerodynamic properties of the wing sections U. S. A. 5, U. S. A. 27, U. S. A. 35A, U. S. A. 35B, Clark Y, R. A. F. 15, and Göttingen 387, as determined at various Reynolds Numbers up to an approximately full scale value in the variable density wind tunnel of the National Advisory Committee for Aeronautics.

It is shown that the characteristics of the wings investigated are affected greatly and in a somewhat erratic manner by variation of the Reynolds Number. In general there is a small increase in maximum lift and an appreciable decrease in drag at all lifts.

Report No. 234, entitled "Three Methods of Calculating Range and Endurance of Airplanes," by Walter S. Diehl, Bureau of Aeronautics, Navy Department.—This report, which was prepared for the National Advisory Committee for Aeronautics, develops new equations which give the range and endurance of airplanes with an accuracy equal to that obtained from a step-by-step integration of the flight. A method of obtaining equally satisfactory results from Breguet's equations, is also given in detail. A third method of calculating range and endurance, derived by the writer for use in routine estimating in the Bureau of Aeronautics, is also given in full.

The report contains tables and curves arranged for convenient use and illustrates the three methods by comparative estimates.

Report No. 235, entitled "Interaction between Air Propellers and Airplane Structures," by W. F. Durand, Stanford University.—The purpose of the investigation, the results of which are presented in this report, was the determination of the character and amount of interaction between air propellers as usually mounted on airplanes and the adjacent parts of the airplane structure—or, more specifically, those parts of the airplane structure within the wash of the propeller and capable of producing any significant effect on propeller performance.

In report No. 177, by Messrs. Lesley and Woods, such interaction between air propellers and certain simple geometrical forms was made the subject of investigation and report. The present investigation aims to carry this general study one stage further by substituting actual airplane structures for the simple geometrical forms.

From the point of view of the present investigation, the airplane structures, viewed as an obstruction in the wake of the propeller, must also be viewed as a necessary part of the airplane and not as an appendage which might be installed or removed at will.

Report No. 236, entitled "Tests on Airplane Fuselages, Floats, and Hulls," by Walter S. Diehl, Bureau of Aeronautics, Navy Department.—This report is a compilation of test data on airplane fuselages, nacelles, airship cars, seaplane floats, and seaplane hulls, prepared by the Bureau of Aeronautics, at the request of the National Advisory Committee for Aeronautics. The discussion of the data includes the derivation of a scale correction curve to be used in obtaining the full scale drag. Composite curves of drag and L/D for floats and hulls are also given.

Report No. 237, entitled "Tests of Thirteen Navy Type Model Propellers," by W. F. Durand, Stanford University.—The tests on these model propellers were conducted at Stanford University under research authorization of the National Advisory Committee for Aeronautics, and were undertaken for the purpose of determining the performance, coefficients, and characteristics for certain selected series of propellers of form and type as commonly used in recent Navy designs.

The first series includes seven propellers of pitch ratio varying by 0.10 from 0.50 to 1.10, the area, form of blade, thickness, etc., representing an arbitrary standard propeller which had shown good results.

The second series covers changes in thickness of blade section, other things equal, and the third series, changes in blade area, other things equal.

These models are all of the standard 36-inch diameter employed in this laboratory.

The dimensions of these model forms are as shown in Figs. 1 to 14.

It will be noticed that propellers A to G form the series on pitch ratio, C, N, I, J the series on thickness of section, and K, M, C, L the series on area.

Report No. 238, entitled "The Effect of Flight Path Inclination on Airplane Velocity," by Walter S. Diehl, Bureau of Aeronautics, Navy Department.—This report was prepared at the request of the National Advisory Committee for Aeronautics in order to supply a systematic study of the relations between the flight velocity V and its horizontal component V_H, in power glides. Curves of V and V_H plotted against the inclination of the flight path θ are given, together with curves, which show the maximum values of V_H and the corresponding values of θ. Curves are also given showing the effect of small departures from the horizontal in high speed performance testing.

Report No. 239, entitled "Power Output and Air Requirements of a Two-Stroke Cycle Engine for Aeronautical Use," by C. R. Paton and Carlton Kemper, National Advisory Committee for Aeronautics.—The investigation herein reported was undertaken by the National

Advisory Committee for Aeronautics at its research laboratory, Langley Field, Va., in order to determine the pressure and amount of air necessary for satisfactory high-speed, two-stroke cycle operation and thus permit the power requirements of the air pump or blower to be determined. Assembly and development of the apparatus and preliminary work in connection with the fuel-injection system were done under the direction of Mr. Robertson Matthews.

The object of this investigation was to determine the pressure and amount of air necessary for satisfactory scavenging and operation of a high-speed, two-stroke cycle engine for aeronautical use, a 5 by 7 inch single-cyclinder Liberty test engine being adapted for the purpose. The fuel and scavenging system consisted of a fuel-injection pump and injection valve, used in conjunction with a separately driven Roots type blower. Tests were conducted at speeds of 1,000, 1,200, and 1,300 revolutions per minute, with air-supply pressures from 2 to 6 lb./sq. in. gauge, and results show, that 53 brake horsepower could be developed at 1,300 revolutions per minute, with a scavenging air pressure of 5.5 lb./sq. in., a specific air consumption of 9 lb./B.HP./hr., and a specific fuel consumption of 0.61 lb./B.HP./hr. Under these conditions 3 horsepower was required to supply the air, resulting in a net power output of 50 brake horsepower. A minimum specific air consumption of 8.4 lb./B.HP. was obtained at this speed with an air-supply pressure of approximately 3.5 lb./sq. in. when developing 41 brake horsepower. Chattering of cam-operated exhaust valves prevented higher speeds.

Based on power output and air requirement here obtained the two-stroke cycle engine would seem to be favorable for aeronautical use. No attempts were made to secure satisfactory operation at idling speeds.

Report No. 240, entitled "Nomenclature for Aeronautics," by the National Advisory Committee for Aeronautics.—This report was prepared by a special conference on aeronautical nomenclature authorized by the executive committee of the National Advisory Committee for Aeronautics at a meeting held on August 19, 1924, at which meeting Dr. Joseph S. Ames was appointed chairman of said conference. The conference was composed of representatives of the National Advisory Committee for Aeronautics and, in response to the committee's invitation, specially appointed representatives officially designated by the Army Air Service, the Bureau of Aeronautics of the Navy Department, the Bureau of Standards, the American Society of Mechanical Engineers, the Society of Automotive Engineers, and the Aeronautical Chamber of Commerce.

This report supersedes all previous publications of the committee on this subject. It is published for the purpose of securing greater uniformity and accuracy in the use of terms relating to aeronautics in official documents of the Government and, as far as possible, in technical and other commercial publications.

Report No. 241, entitled "Electrical Characteristics of Spark Generators for Automotive Ignition," by R. B. Brode, D. W. Randolph, and F. B. Silsbee, Bureau of Standards.—This paper reports the results of an extensive program of measurements on 11 ignition systems differing widely in type. The results serve primarily to give representative data on the electric and magnetic constants of such systems, and on the secondary voltage produced by them under various conditions of speed, timing, shunting resistance, etc. They also serve to confirm certain of the theoretical formulas which have been proposed to connect the performance of such systems with their electrical constants, and to indicate the extent to which certain simplified model circuits duplicate the performance of the actual apparatus.

Report No. 242, entitled "Characteristics of a Twin-Float Seaplane During Take-Off," by John W. Crowley, jr., and K. M. Ronan, National Advisory Committee for Aeronautics.—At the request of the Bureau of Aeronautics, Navy Department, an investigation has been made by the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics of the planing and get-away characteristics of three representative types of seaplanes, namely, single float, boat, and twin float. The experiments carried out on the single float and boat types have been reported on previously. This report covers the investigation conducted on the twin-float seaplane, the *DT-2*, and includes as an appendix, a brief summary of the results obtained on all three tests.

The fundamental take-off characteristics of the *DT–2* seaplane (twin float) are similar to those of the *N–9H* (single float) and the *F–5L* (boat type). At low-water speeds, 20 to 25 miles per hour, the seaplane trims by the stern and has a high resistance. Above these speeds the longitudinal control becomes increasingly effective until, with a gross load of 6,000 pounds, it is possible to get away at angles of attack of 8° to 14° with corresponding speeds of 56 to 46 miles per hour. It was further determined that an increase in the load caused little if any change in the water speed at which the maximum angle and resistance occurred, but that it did produce an increase in the maximum angle.

Report No. 243, entitled "A Preliminary Study of Fuel Injection and Compression Ignition as Applied to an Aircraft Engine Cylinder," by Arthur W. Gardiner, National Advisory Committee for Aeronautics.—This report summarizes some results obtained with a single-cylinder test engine at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics, during a preliminary investigation of the problem of applying fuel injection and compression ignition to aircraft engines. For this work a standard Liberty engine cylinder was fitted with a high compression, 11.4 : 1 compression ratio, piston, and equipped with an airless injection system, including a primary fuel pump, an injection pump, and an automatic injection valve.

The results obtained during this investigation have indicated the possibility of applying airless injection and compression ignition to a cylinder of this size, 5-inch bore by 7-inch stroke, when operating at engine speeds as high as 1,850 revolutions per minute, although the unsuitability of the Liberty cylinder form of combustion chamber for compression ignition research probably accentuated the difficulties to be overcome. No difficulty was experienced in metering and injecting the small quantities of fuel required. A minimum specific fuel consumption with Diesel engine fuel oil of 0.30 pound per indicated horsepower hour was obtained when developing about 16 brake horsepower at 1,730 revolutions per minute. Specific fuel consumption increased for higher loads at these speeds. A maximum power output of 29.7 brake horsepower at 1,700 revolutions per minute was obtained, but could not be maintained for more than one-half minute due to piston failure. Mean effective pressures approaching standard aircraft engine practice could not be obtained, due in part, it was attributed, to the unsuitable form of the Liberty cylinder combustion chamber. Excessive maximum combustion pressures were encountered when developing only about 60 pounds B. M. E. P. at 1,700 revolutions per minute, and piston life was very short. The engine could be idled with regular firing at 400 revolutions per minute, but acceleration under load was not satisfactory, due probably to the fixed timing of injection during any particular run.

Report No. 244, entitled "Aerodynamic Characteristics of Airfoils—IV," by National Advisory Committee for Aeronautics.—This collection of data on airfoils has been made from the published reports of a number of the leading aerodynamic laboratories of this country and Europe. The information which was originally expressed according to the different customs of the several laboratories is here presented in a uniform series of charts and tables suitable for the use of designing engineers and for purposes of general reference.

It is a well-known fact that the results obtained in different laboratories, because of their individual methods of testing, are not strictly comparable even if proper scale corrections for size of model and speed of test are supplied. It is, therefore, unwise to compare too closely the coefficients of two wing sections tested in different laboratories. Tests of different wing sections from the same source, however, may be relied on to give true relative values.

The series of airfoils designated N. A. C. A.–M1 to N. A. C. A.–M27 were tested in the variable density wind tunnel of the National Advisory Committee for Aeronautics at a pressure of approximately 20 atmospheres.

The absolute system of coefficients has been used, since it is thought by the National Advisory Committee for Aeronautics that this system is the one most suited for international use and yet it is one from which a desired transformation can be easily made. For this purpose a set of transformation constants is given.

Each airfoil section is given a reference number, and the test data are presented in the form of curves from which the coefficients can be read with sufficient accuracy for designing purposes. The dimensions of the profile of each section are given at various stations along the chord in per cent of the chord, the latter also serving as the datum line. When two sets of ordinates are necessary, on account of taper in chord or ordinate, those for the maximum section (at center of span) are given on the individual characteristic sheets, while those for the tip (dotted) section are given in separate tables. Where the ratio of ordinate to chord remains constant the one set of ordinates applies to both center and tip section. The shape of the section is also shown with reasonable accuracy to enable one to more clearly visualize the section under consideration, together with its characteristics.

The authority for the results here presented is given as the name of the laboratory at which the experiments were conducted, with the size of model, wind velocity, and year of test.

Report No. 245, entitled "Meteorological Conditions along Airways," by W. R. Gregg, Weather Bureau.—This report was prepared at the suggestion of and for publication by the National Advisory Committee for Aeronautics, and is an attempt to show the kind of meteorological information that is needed, and is in part available, for the purpose of determining operating conditions along airways. In general, the same factors affect these operating conditions along all airways though in varying degree, depending upon their topographic, geographic, and other characteristics; but in order to bring out as clearly as possible the nature of the data available, a specific example is taken, that of the Chicago-Fort Worth airway, on which regular flying begins this year.

Report No. 246, entitled "Tables for Calibrating Altimeters and Computing Altitudes Based on the Standard Atmosphere," by W. G. Brombacher, Bureau of Standards.—During 1925 the assumption of an isothermal atmosphere which was in general use as the standard for the calibration of altimeters in the United States was replaced by a standard atmosphere which assumes an altitude-temperature relation closely corresponding to the average of upper air observations at latitude 40° in this country. The same standard atmosphere had already been adopted somewhat earlier in the United States as the aircraft performance standard.

National Advisory Committee for Aeronautics Technical Reports Nos. 147 and 218 give necessary constants, tables, and information. However, neither of these reports includes all of the tables required for the computation of actual altitudes nor those readily suitable for use in calibrating altimeters, since the altitude intervals for which data are given are not sufficiently small. The present report has been prepared specifically for these purposes.

The formulas which define the standard atmosphere are given in this report, together with other formulas giving the corrections to be applied to the standard altitude in order to obtain the actual altitude when the necessary observations of pressure and temperature are available.

The tables necessary for the use of this standard atmosphere in calibrating altimeters and in computing altitudes form the principal part of this report. In Table I are given the standard altitudes at pressure intervals of 0.1 millimeter of mercury in the range 87 to 200 millimeters of mercury and at intervals of 0.2 millimeter of mercury in the range 200 to 790 millimeters of mercury. In Table II standard altitudes are given at intervals of 0.01 inch of mercury in the range 3.4 to 31.09 inches of mercury. In Table III are given the pressure in inches and millimeters of mercury, the temperature, the mean temperature, and the corresponding isothermal altitude at every 500-foot interval of standard altitude in the range −1,000 to +50,000 feet. Temperature corrections for use in computing altitudes from observed pressures and temperatures are given in Table IV.

An example of the computation of actual altitude from the necessary observations of pressure and temperature is also included.

Report No. 247, entitled "Pressure of Air on Coming to Rest from Various Speeds," by A. F. Zahm, Construction Department, Washington Navy Yard.—The text gives theoretical formulas from which is computed a table for the pressure of air on coming to rest from various speeds, such as those of aircraft and propeller blades. Pressure graphs are given for speeds from 1 centimeter-second up to those of swift projectiles.

The present treatment slightly modified was prepared for the Bureau of Aeronautics, Navy Department, February 17, 1926, and by it was submitted for publication to the National Advisory Committee for Aeronautics.

Report No. 248, entitled "The Corrosion of Magnesium and the Magnesium Aluminum Alloys Containing Manganese," by J. A. Boyer, American Magnesium Corporation.—The tentative conclusions drawn from the experimental facts of this investigation are as follows:

The overvoltage of pure magnesium is quite high. On immersion in salt water the metal corrodes with the liberation of hydrogen until the film of corrosion product lowers the potential to a critical value. When the potential reaches this value it no longer exceeds the theoretical hydrogen potential plus the overvoltage of the metal. Rapid corrosion consequently ceases. When aluminum is added, especially when in large amounts, the overvoltage is decreased and hydrogen plates out at a much lower potential than with pure magnesium. The addition of a small amount of manganese raises the overvoltage back to practically that of pure metal, and the film is again protective.

Report No. 249, entitled "A Comparison of the Take-Off and Landing Characteristics of a Number of Service Airplanes," by Thomas Carroll, National Advisory Committee for Aeronautics.—This investigation, which is a continuation of Technical Report No. 154, "A Study of Taking Off and Landing an Airplane," follows very closely the earlier methods and covers a number of service airplanes, whereas the previous report covered but one, the JN-4h.

In addition to the air speed, acceleration, and control positions as given in report No. 154, information is here given regarding the distance run and the ground speed for the various airplanes during the two maneuvers.

Report No. 250, entitled "Description of the N. A. C. A. Universal Test Engine and Some Test Results," by Marsden Ware, National Advisory Committee for Aeronautics.—This report describes the 5-inch bore by 7-inch stroke single-cylinder test engine used at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics, in laboratory research on internal-combustion engine problems and presents some results of tests made therewith.

The engine is arranged for variation over wide ranges of the compression ratio and lift and timing of both inlet and exhaust valves while the engine is in operation. Provision is also made for the connection of a number of auxiliaries. These features tend to make the engine universal in character and especially suited for the study of certain problems involving change in compression ratio, valve timing and lift.

Incidental to investigations of carburetor and fuel-injection engine problems, considerable data have been obtained which indicate the effect of changes of compression ratio on friction horsepower and volumetric efficiency. From this and some other work, it appears that with a change in compression ratio from 5 to 13, the friction horsepower obtained by motoring the engine increases by about 15 per cent, while the volumetric efficiency taken during power runs is practically unchanged.

The results of some tests are presented also that show the power obtained when operating as a carburetor engine on aviation gasoline at compression ratios in excess of that which will permit full throttle as a normal engine and controlling detonation by throttling the intake charge and by varying the inlet valve timing. For fixed compression ratios in these tests throttling gave the least power while variation of the inlet valve closing time with the opening time kept fixed gave the greatest power for the conditions tried.

Report No. 251, entitled "Approximations for Column Effect in Airplane Wing Spars," by Edward P. Warner and Mac Short, Massachusetts Institute of Technology.—The significance attaching to "column effect" in airplane wing spars has been increasingly realized with the passage of time, but exact computations of the corrections to bending moment grooves resulting from the existence of end lobes are frequently omitted because of the additional labor involved in an analysis by rigorously correct methods. The present report, submitted for publication by the National Advisory Committee for Aeronautics, represents an attempt to provide for approximate column effect corrections that can be graphically or otherwise expressed so as to be applied with a minimum of labor. Curves are plotted giving approximate values of the correction factors for single and two bay trusses of varying proportions and with various relationships between axial and lateral loads. It is further shown from an analysis of those curves that rough but useful approximations can be obtained from Perry's formula for corrected bending moment, with the assumed distance between points of inflection arbitrarily modified in accordance with rules given in the report.

The discussion of general rules of variation of bending stress with axial load is accompanied by a study of the best distribution of the points of support along a spar for various conditions of loading.

Report No. 252, entitled "The Direct Measurement of Engine Power on an Airplane in Flight with a Hub Type Dynamometer," by W. D. Gobe and M. W. Green, National Advisory Committee for Aeronautics.—This report describes tests made at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics, to obtain direct measurements of engine power in flight. Tests were made with a Bendemann hub dynamometer installed on a modified DH–4 airplane, Liberty 12 engine, to determine the suitability of this apparatus.

This dynamometer unit, which was designed specially for use with a Liberty 12 engine, is a special propeller hub in which is incorporated a system of pistons and cylinders interposed between the propeller and the engine crank shaft. The torque and thrust forces are balanced by fluid pressures, which are recorded by instruments in the cockpit.

These tests have shown the suitability of this type of hub dynamometer for measurement of power in flight and for the determination of the torque and power coefficients of the propeller.

Report No. 253, entitled "Drag and Pressure-Drag of Simple Quadrics," by A. F. Zahm, construction department, Washington Navy Yard.—In this text are given the pressure distribution and resistance found by theory and experiment for simple quadrics fixed in an infinite uniform stream of practically incompressible fluid. The experimental values pertain to air and some fluids, especially water; the theoretical refers sometimes to perfect, again to viscid fluids. For the cases treated the concordance of theory and measurement is so close as to make a summary of results desirable. Incidentally formulas for the velocity at all points of the flow field are given, some being new forms for ready use derived in a previous paper and given in Table I.

Report No. 254, entitled "Distribution of Pressure Over a Model of the Upper Wing and Aileron of a Fokker D–VII Airplane," by A. J. Fairbanks, National Advisory Committee for Aeronautics.—This report describes tests made in the atmospheric wind tunnel of the National Advisory Committee for Aeronautics, for the purpose of determining the distribution of pressure over a model of the tapered portion of the upper wing and the aileron of a Fokker D–VII airplane. Normal pressures were measured simultaneously at 74 points distributed over the wing and ailerons. Tests were made throughout the useful range of angles of attack with aileron settings ranging from $-20°$ to $+20°$. The results are presented graphically.

It was found that the pressure distribution along the chord is in general similar to that of thick tapered airfoils previously tested. The maximum resultant pressure recorded was five times the dynamic pressure. The distribution of the air load along the span may be assumed to be uniform for design purposes.

Aileron displacements affect the pressures forward to the leading edge of the wing and may increase the air load on the outer portion of the wing by a considerable amount. With the wing at large angles of attack, the overhanging portion of the aileron creates usually a burbled flow and therefore a large drag. The balance reduces the control stick forces at small angles of attack for all aileron displacements. At large angles of attack it does this for small displacements only. With the airplane at its maximum speed, an angle of attack of 18°, and a down aileron displacement of 20°, the bending moment tending to break off the overhanging portion of the aileron will be greater than that caused by a uniform static load of 35 pounds per square foot.

Report No. 255, entitled "Pressure Distribution Over Airfoils at High Speeds," by L. J. Briggs and H. L. Dryden, Bureau of Standards.—This report deals with the pressure distribution over airfoils at high speeds, and describes an extension of an investigation of the aerodynamic characteristics of certain airfoils which was presented in N. A. C. A. Technical Report No. 207.

The results presented in report No. 207 have been confirmed and extended to higher speeds through a more extensive and systematic series of tests. Observations were also made of the air flow near the surface of the airfoils, and the large changes in lift coefficients were shown to be associated with a sudden breaking away of the flow from the upper surface.

The tests were made on models of 1-inch chord and comparison with the earlier measurements on models of 3-inch chord shows that the sudden change in the lift coefficient is due to compressibility and not to a change in the Reynolds number. The Reynolds number still has a large effect, however, on the drag coefficient.

The pressure distribution observations furnish the propeller designer with data on the load distribution at high speeds, and also give a better picture of the airflow changes.

Report No. 256, entitled "The Air Forces on a Systematic Series of Biplane and Triplane Cellule Models," by Max M. Munk, National Advisory Committee for Aeronautics.—The air forces on the largest systematic series of biplane and triplane cellule models ever published, measured in the atmospheric density tunnel of the Langley Memorial Aeronautical Laboratory, are the subject of this report. The tests consist in the determination of the lift, drag, and moment of each individual airfoil in each cellule, mostly with the same wing section.

The magnitude of the gap and of the stagger is systematically varied; not, however, the decalage, which is zero throughout the tests. Certain check tests with a second wing section make the tests more complete and the conclusions more convincing.

The results give evidence that the present Army and Navy specifications for the relative lifts of biplanes are good. They furnish material for improving such specifications for the relative lifts of triplanes. A larger number of factors can now be prescribed to take care of different cases.

LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

No.

228. The Flettner Rotor Ship in the Light of the Kutta-Joukowski Theory and of Experimental Results. By Frank Rizzo.
229. An Altitude Chamber for the Study and Calibration of Aeronautical Instruments. By H. J. E. Reid and Otto E. Kirchner.
230. The Spacing of Orifices for the Measurement of Pressure Distributions. By Max M. Munk.
231. The Resistance to the Steady Motion of Small Spheres in Fluids. By R. A. Castleman.
232. The Lateral Failure of Spars. By Stevens Bromley and William H. Robinson, jr.
233. N. A. C. A. Flight-Path-Angle and Air-Speed Recorder. By Donald G. Coleman.
234. An Investigation of the Characteristics of Steel Diaphragms for Automatic Fuel-Injection Valves. By W. F. Joachim.
235. Propeller Design. By Fred E. Weick. Part I. Practical Application of the Blade Element Theory.
236. Propeller Design. By Fred E. Weick. Part II. Extension of Test Data on a Family of Model Propellers by Means of the Modified Blade Element Theory.
237. Propeller Design. By Fred E. Weick. Part III. A Simple System Based on Model Propeller Test Data.
238. Propeller Design. By Fred E. Weick. Part IV. A Simple Method for Determining the Strength of Propellers.
239. Steam Power Plants in Aircraft. By E. E. Wilson.
240. The N. A. C. A. CYH Airfoil Section. By George J. Higgins.
241. Tests of Several Bearing Materials Lubricated by Gasoline. By W. F. Joachim and Harold W. Case.
242. Improving the Performance of a Compression Ignition Engine by Directing Flow of the Inlet Air. By Carlton Kemper.

No.
243. The Characteristics of the N. A. C. A. M–12 Airfoil Section. By George J. Higgins.
244. Navy Propeller Section Characteristics as Used in Propeller Design. By Fred E. Weick.
245. Report on Tests of Metal Model Propellers in Combination with a Model VE–7 Airplane. By E. P. Lesley.
246. Test of a Model Propeller with Symmetrical Blade Sections. By E. P. Lesley.
247. The Drag of Airships—Part I. By Clinton H. Havill.

LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

No.
332. Concrete Airship Sheds at Orly, France. By Freyssinet. Part I. General Aspect of the Problem; Basic Principles of the Final Project; Principal Structural Elements. Translation from "Le Genie Civil," September 22 and 29, 1923.
333. Concrete Airship Sheds at Orly, France. By Freyssinet. Part II. Supporting Structure and Method of Moving; Mechanism for Moving and Centering; Apparatus for Handling the Materials; Remarks on Construction Details.
334. Theory of Flapping Flight. By Alexander Lippisch. Translation from "Flugsport," June 17, 1925.
335. Schütte-Lanz Airship Projects after the War. By Georg Weiss. Translation from "Schiffbau," May 27, 1925.
336. Pressure Distribution on Joukowski Wings. By Otto Blumenthal.
Graphic Construction of Joukowski Wings. By E. Trefftz. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," May 31, 1913.
337. A Method for the Direct Determination of Wing-Section Drag. By A. Betz. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," February 14, 1925.
338. Recent Progress in the Theoretical Deduction of Airplane Wings. By M. Panetti. Translation from "Rivista Aeronautica," July, 1925.
339. Aerodynamic Characteristics of Aircraft with Reference to their Use. By M. Panetti. Translation from "L'Ala d'Italia," April, 1925.
340. An Introduction to the Helicopter. By Alexander Klemin. From "Mechanical Engineering," Mid-November, 1924.
341. Strength Calculations on Airplanes. By A. Baumann. Translation from "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt," July, 1925.
342. Wire Suspensions in Wind Tunnel Experiments. By Jean Kerneis. Translation from "L'Aerophile," September 1–15, 1925.
343. Potential Flow in Engine Valves. By Bruno Eck. Translation from "Zeitschrift für angewandte Mathematik und Mechanik," Vol. IV, 1924.
344. Calculation of Tubular Radiators of the Automobile Type. By L. Richter. Translation from "Zeitschrift für angewandte Mathematik und Mechanik," August, 1925.
345. Photographic Time Studies of Airplane Paths. By A. G. Von Baumhauer. Translation of Report V 79, from "Verslagen en Verhandelingen van den Rijks-Studiedienst voor de Luchtvaart," Vol. III, 1925.
346. Behm Acoustic Sounder for Aircraft. Translation from "Flugsport," November 11, 1925.
347. Two-Stroke-Cycle Engines for Airplanes. By J. Jalbert. Translation from "L'Aeronautique," July and August, 1925.
348. Protection of Wooden Airplane Parts against Moisture by Means of Varnish. By E. B. Wolff and L. J. G. Van Ewijk. Translation of Report M 14 A from "Verslagen en Verhandelingen van den Rijks-Studiedienst voor de Luchtvaart," Vol. III, 1925.
349. The Metal Construction of Airplanes—Its Advantages—Its Present State—Its Future. By M. De Woitine. Paper read before the Institution of Aeronautical Engineers, December 15, 1925.
350. Change of 180° in the Direction of a Uniform Current of Air. Prepared for publication by J. Bonder.
351. Kirsten-Boeing Propeller. By H. Sachse. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," January 14, 1926.

No.

352. Functioning of Reduction Gears on Airplane Engines. By Raffaelli Matteucci. Translation from "Notiziario Tecnico," December, 1925.
353. Recent Experiments with Large Seaplanes. By Adolf Rohrbach. Translation from "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt," July 1925.
354. Tests for Determining the Effect of a Rotating Cylinder Fitted into the Leading Edge of an Airplane Wing. By E. B. Wolff and C. Koning. Translation of Report A. 105 of the "Rijks-Studiedienst voor de Luchtvaart," Amsterdam.
355. Slip Stream Effect. By Charles N. Montieth. From "Slipstream," December, 1925.
356. The Fundamental Principles of High-Speed Semi-Diesel Engines. By Doctor Buchner. Part I. A General Discussion of the Subject of Fuel Injection in Diesel Engines and Detailed Descriptions of many Types of Injection Nozzles. Translation from "Jahrbuch der Brennkrafttechnischen Gesellschaft," Vol. V, 1924.
357. The Fundamental Principles of High-Speed Semi-Diesel Engines. By Doctor Buchner. Part II. A Discussion of the Semi-Diesel Principle and its Application to Various Types of Solid-Injection Engines. Translation from "Jahrbuch der Brennkrafttechnischen Gesellschaft," Vol. V, 1924.
358. The Fundamental Principles of High-Speed Semi-Diesel Engines. By Doctor Buchner. Part III. A Discussion of Fuel Mixing and Ignition, with Special Reference to Engines with Precombustion Chambers. Translation from "Jahrbuch der Brennkrafttechnischen Gesellschaft, " Vol. V, 1924.
359. Flight Tests on Airplanes. By Heinrich Koppe. Translation from "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt," July, 1925.
360. Mixing and Ignition in Supercharged Engines. By A. E. Thierman. Translation from "Der Motorwagen," December 10, 1925.
361. Metal Airplane Construction. Translation of paper read at the Third International Congress of Aerial Navigation held at Brussels in October, 1925.
362. Experimental Investigation of the Physical Properties of Medium and Heavy Oils, their Vaporization and Use in Explosion Engines. By Fritz Heinlein. Translation from "Der Motorwagen," October 10, 1925.
363. Experimental Investigation or the Physical Properties of Medium and Heavy Oils, their Vaporization and Use in Explosion Engines—Part II. By Fritz Heinlein. Translation from "Der Motorwagen," October 31, December 20, 1925; February 10, 1926.
364. Kinetographic Flow Pictures. By L. Prandtl and O. Tietjens. Translation from "Die Naturwissenschaften," Vol. XIII.
365. Tasks of Air Flow Research. By L. Prandtl. Translation from "Die Naturwissenschaften," Vol. XIV, No. 16.
366. Calculation of Combining Effects in the Structure of Airplane Wings. A Rational Basis for Estimating the Reduction in the Design Load on Wing Beams Due to the Influence of Ribs and Covering toward Causing the Beams to Deflect Together. By K. Thalau. Translation from "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt," July, 1925.
367. Application of the "Magnus Effect" to the Wind Propulsion of Ships. By L. Prandtl. Translation from "Die Naturwissenschaften," Vol. XIII, June 2, 1925.
368. Metal Spars. By J. D. Haddon. From "Flight," February 25, 1926.
369. Tests on an Airfoil with Two Slots Suitable for an Aircraft of High Performance—Lift, Drag, Rolling, and Yawing Moment Measurements. By F. Handley Page. From "Flight," January 28, 1926.
370. Development of Light and Small Airplanes. By G. Lachmann. Translation from "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt," July, 1925.

No.

371. On the Knocking of Gasoline Engines. By Ludwig Richter. Translation from "Der Motorwagen," November 20, 1925; January 20, May 10, June 20, 1926.
372. First Experiences with the Rotating Laboratory. By L. Prandtl. Translation from "Naturwissenschaften," May 7, 1926, Vol. XIV.
373. Tail planes. By L. Constantin. Translation from "L'Aerophile," May 1–15, 1926.
374. Experiments with an Airfoil from which the Boundary Layer is Removed by Suction. By J. Ackeret, A. Betz, and O. Schrenk. Translation from "Vorlaufige Mitteilungen der Aerodynamischen Versuchsanstalt zu Göttingen," No. 4, November, 1925.
375. Effect of Roughness on Properties of Airfoils. By O. Schrenk. Translation from "Vorlaufige Mitteilungen der Aerodynamischen Versuchsanstalt zu Göttingen," No. 4, November, 1925.
376. Designing Seaplane Hulls and Floats. By Lieut. Benoit. Translation from "L'Aeronautique," June, 1926.
377. The Belgian Aerotechnical Laboratory at Rhode-Saint-Genèse. Translation from Bulletin of the Technical Service of Aeronautics (Brussels), January, 1926.
378. Recent Developments in the Construction and Operation of All-Metal Airplanes. By C. Dornier. Translation from "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt," May, 1926
379. Digest of Some of the Speeches Made at the Fifteenth Regular Meeting of the "Wissenschaftliche Gesellschaft für Luftfahrt," June 17, 1926, in Dusseldorf, Germany. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," July 14, 1926.
380. Experiments on Autorotation. By E. Anderlik. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," August 28, 1926.
381. Take-Off Distance for Airplanes. By A. Pröll. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," August 14, 1926.

LIST OF AIRCRAFT CIRCULARS ISSUED DURING THE PAST YEAR

No.

1. Lioré-Olivier Airplane—Type 12 Night-Bomber or Type 20 Commercial. By J. Serryer. Translation from "Les Ailes," January 28, 1926.
2. The Pander Light Biplane—A School Two-Seater with 45 Horsepower Anzani Engine. From "Flight," April 1, 1926.
3. The Vickers "Vendace"—A Land or Sea Training Biplane. From "Flight," March 18, 1926.
4. German Training Airplane, Arado *Ar. S. I.* By G. Manigold. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," March 28, 1926.
5. The Short S. 7 "Mussel"—A Training Seaplane with 65 horsepower "Cirrus" Engine. From "Flight," March 11, 1926.
6. All-Metal Junkers Airplane, Type F 13. Translation from the German.
7. Two "Gloster" Airplanes: The *Grouse II*, Two-Seat Training Airplane; the *Grebe II*, Single-Seat Fighter. From "Flight," November 19, 1925.
8. The Albatros *L 72A*, A German Newspaper Carrier with Slotted Wings. From "Flight," April 15, 1926.
9. Wibault Two-Seat Monoplane *8 C2*, An All-Metal Pursuit and Observation Airplane. By J. Serryer. From "Les Ailes," May 13, 1926, and "The Aeroplane," April 14, 1926.
10. A New De Havilland Commercial Airplane, The *D. H. 66*, with Three Bristol "Jupiter" Engines. From "Flight," June 10, 1926.
11. The Blackburn *Sprat*, A Training Airplane Convertible into Landplane or Seaplane. From "Flight," May 27, 1926.
12. Farman Monoplane *F. 170*, Commerical Airplane with One 500 Horsepower Farman Engine. By J. Serryer. Translation from "Les Ailes," April 8, 1926.
13. Heinkel Airplane *H. D. 39* for Carrying Newspapers. Translation from "Flugsport," May 1, 1926.

No.

14. The Armstrong-Whitworth *Argosy*, The Latest Three-Engined Commercial Airplane. From "Flight," July 1 and August 5, 1926.
15. The Farman Commercial Airplane *Jabiru*. Translation from the French.
16. Albatros Commercial Airplane *L 73*. By Karl Ruhl and Hasso Wiederhold. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," July 28, 1926.

BIBLIOGRAPHY OF AERONAUTICS

During the year 1926 the committee issued a bibliography of aeronautics for the year 1923. It had previously issued bibliographies for the years 1909 to 1916, 1917 to 1919, 1920 to 1921, and 1922. A bibliography for the year 1924 is now in the hands of the printer and should be ready for distribution during the coming year.

Citations of the publications of all nations are included in the language in which the publications originally appeared. The arrangement is in dictionary form, with author and subject entry, and one alphabetical arrangement. Detail in the matter of subject reference has been omitted on account of cost of presentation, but an attempt has been made to give sufficient cross reference to make possible the finding of items in special lines of research.

PART V

THE PRESENT STATUS OF AVIATION

THE PRESENT STATE OF TECHNICAL DEVELOPMENT

AERODYNAMICS

Reviewers of the progress in aerodynamics in the past have usually found that the theory had advanced at a greater rate than its practical application. This is a natural phase in the development of a new science. However, it is apparent that the time has now arrived when the main theoretical foundation has been laid and we may expect in the future to find extensions of and additions to existing theory rather than new fundamental conceptions. We are therefore entering into a phase of refined and applied theory, as shown by the developments during the past year. This phase demands that theory be developed in detail to fit particular requirements or to explain unusual phenomena.

Considering first the general theories of air flow and their practical application, it is found that satisfactory progress has been made. One of the most important contributions made by theory to practice in recent years is the "wall effect" correction, by means of which the interference between a model and the wind-tunnel walls can be calculated. During the past year these corrections have been proved valid not only by check calculations based on more refined assumptions and methods but also by numerous practical applications whereby the test results from different wind tunnels were brought into excellent agreement. Outstanding applications of theory to practice are to be found in the reports of the British Aeronautical Research Committee, while considerable work has also been done along similar lines at the Langley Memorial Aeronautical Laboratory, where numerous checks on the wing theory have been made.

WIND TUNNELS.—As more data are accumulated on wind tunnels and their limitations, additional justification is found for reliance on them as an invaluable adjunct to design. The failure to recognize the existence of large scale effect and the failure to make proper allowance therefor in the interpretation of test results has frequently led to conclusions very much in error. For example, it has been shown conclusively during the past year that the variable-density wind tunnel gave data at high Reynolds numbers which were correct only when the model was a true geometrical scale reproduction, this feature extending even to the surface finish on airfoil or wing models. Along similar lines it has been shown that tests on airplane models in atmospheric wind tunnels are of little value unless scale corrections or the equivalent of scale corrections are made. This matter is now being satisfactorily handled in some wind tunnels by the elimination, through special tests, of the scale effect on struts, wires, and fittings.

FREE-FLIGHT TEST—*Investigation of spinning.*—An increasing interest is being shown in free-flight research. This is due in part to the excellent results which have been obtained by the use of new and improved recording instruments and devices and in part to the stimulus brought about by the general discussions which have followed the discovery that certain types of airplanes could be put into spins from which recovery was very difficult. These spins, which are characterized by an unusually rapid rotation at a high angle of attack, have been under investigation in this country and in England for almost two years and the solution now seems well in hand. Analyses of this type of spin from wind-tunnel and flight-test data indicate that equilibrium in the unusual flat attitude is due to precessional moments brought about by an excessively rapid rotation and that the cure should be found either in a reduction of the rate of rotation or in a new mass distribution giving the proper relations between the moments of inertia about the principal axes. The correctness of these deductions has been demonstrated by tests in which models of the airplanes have been dropped from a height in such a manner as to fall into spins. The motion is studied from standard and ultrarapid moving pictures.

These models were constructed of balsa wood in such a manner that the mass distribution was the same as in the full-sized airplane. Provision was also made for changing the mass distribution. This method of studying the behavior of airplanes in maneuvers has apparently opened an entirely new field in aerodynamic research.

Pressure distribution and loading.—The questions of loading, such as the distribution of loads between the wings of a biplane, distribution of load along the span, local loadings, and loads on control surfaces, have always received considerable attention, but as a general rule no more than was demanded for immediate design requirements. With the demand for refinements in design it is inevitable that more free-flight tests along these lines will be required. It is gratifying to record that the testing program at the Langley Memorial Aeronautical Laboratory contains a number of important pressure-distribution studies and that considerable data are now available for design use.

In this connection, attention is invited to the fact that pressure-distribution measurements have long been known to yield data not obtainable by other means, but the difficulties involved have prevented this field of testing from developing to a degree commensurate with its worth. With the advent of the special photographic recording instruments designed and built at the Langley Memorial Aeronautical Laboratory it became possible to secure a continuous and simultaneous pressure record for any desired number of points on the airplane and for any desired length of time. These instruments enable an almost unlimited amount of data to be obtained on a single flight, with the obvious result that the only limit now imposed is that of labor involved in tabulating and analyzing the test data. It is the opinion of many who are in touch with these developments that pressure-distribution studies made with the new equipment offer the most logical and most promising method of increasing the knowledge of design requirements, particularly since it has been demonstrated that in no case does the recorded pressure vary more than a few per cent from the true pressure.

Supplementing the free-flight pressure-distribution data, a very important wind-tunnel research on the distribution of loading between the wings of biplanes and triplanes has been completed during the past year. This research covers systematically the effect of gap, stagger, and wing section on the load distribution, and, in connection with the excellent work previously done along similar lines in Germany and England, it is believed that present needs will be fully met.

Control at low speeds.—Control at low speeds has now been under investigation for several years in England and real progress has been made through the demonstration of several methods of securing control in stalled flight. This investigation has been so thorough and complete that any extensive work in this country would be largely a duplication of effort. The National Advisory Committee for Aeronautics has therefore adopted the general policy of limiting low-speed-control tests as far as practicable to features not covered in the British tests, or to flight tests on special devices. In accordance with this policy tests have been made by the Army and Navy on the Savage-Bramson antistall gear, the Frise aileron, and differential ailerons of various types, with and without the "spoiler" gear. The British tests on the Hill tailless airplane and the La Cierva autogiro have been watched with great interest, in view of the potential value of these types for special purposes.

During the past year flight tests have been made at the Langley Memorial Aeronautical Laboratory to determine landing and take-off runs, ground effect, and the effect of supercharging on performance. The preliminary reports of these tests, which are now available are of considerable general interest as well as technical value.

Scale Effect.—The investigation and comparison of model and full-scale data have continued both here and abroad. In this country tests, both model and full scale, have been under way for some time on the Sperry messenger airplane fitted with different wings, while the Army and Navy have conducted a number of design studies along similar lines. The same problem has been under investigation in England to an even greater extent and a number of reports have been issued by the British Aeronautical Research Committee.

The variable-density wind tunnel is now supplying data of great importance in design and design analysis. During the past year several features demanding further attention have been brought out. For example, the tests have shown that the scale effect in atmospheric tunnels may be very favorable for certain wing sections and unfavorable for others. This tendency had previously been noted, but its magnitude was greater than expected. It has also been shown conclusively that the characteristics of certain wing sections are extremely sensitive to slight alterations in camber or surface conditions, thus explaining the poor performance of certain designs and the decrease in performance after a long period of service. It is believed that a fruitful field for research lies in the determination of those sections which have a stable flow with good aerodynamic properties.

LIGHTER-THAN-AIR CRAFT.—Among the lighter-than-air investigations, the determination of pressure distribution on the *Los Angeles* is by far the most important. The data from these tests are expected to supply a large part of the background for the design of rigid airships in the future. Tests are now under way in the variable-density wind tunnel on a series of airship models in which the ratio of length to diameter is varied over a wide range in order to determine the best ratios for various volumes.

METAL PROPELLERS.—One of the most pronounced tendencies noted during the past year is the general adoption of metal propellers. Continued testing in service has proved that the thin-section metal propellers not only give higher efficiencies than the conventional wooden designs but that the higher efficiency is accompanied by greater economy. The problems involved in propeller design, however, have become more numerous and more difficult, for the metal propeller shows a decided tendency to flutter and the deformations under load are large. These defects have been remedied for the time being by cut-and-try methods pending the completion and operation of the propeller research equipment of this committee.

TESTS OF MODEL PROPELLERS.—Additional model data on propeller characteristics and interference effects have been made available during the year, but there is almost universal agreement among designers that the differences in deformation between model and full scale are so great that only full-scale tests will bring out the improvements which may be expected in the future. It should be noted in this connection, however, that those comparisons between model and full scale which have been completed show excellent agreement in most cases and lead to the conclusion that model data obtained under proper conditions may be used with confidence.

FIELDS FOR FUTURE RESEARCH.—In concluding this review of aerodynamical progress, it is desired to emphasize the fact that all indications now point to a stabilized progress, in which improvements are restricted largely to refinement of design. The possibilities in refinement of design are very great, since there is no part of an airplane which is not subject to improvement structurally and aerodynamically. For example, the subject of slots and flaps has long been under investigation and excellent airplanes have been built incorporating them, but these devices alone can not convert a poor airplane into a good one, since they merely give a moderate improvement. The most promising fields for future research are: First, along the lines which increase our knowledge of forces and force distributions, thus leading to more efficient structures and greater safety through better control; second, in the development of better wing sections free from unstable flow characteristics; and third, in the adaptation of special devices, such as slots, flaps and other devices to the improved wing sections.

AIRPLANE STRUCTURES

TREND OF DESIGN—*Standardization of types.*—The tendency toward standardization of types for particular services has continued. For commercial service where air speeds are low and efficiency is the primary requirement, the tendency is toward the use of monoplanes. In the lighter and faster types of commercial airplanes, the biplane is used, as it has in general the advantages of maneuverability and compactness of form.

For military airplanes, particularly of the lighter types using semiinternally braced, moderately thick wings, the biplane combinations predominate. This type of wing cellule is used not only in the best types of pursuit airplanes but also in observation and bombing types.

Number and location of engines.—Last year there appeared to be a tendency toward the use of single engines of 800 horsepower or more in large bombing airplanes. Of late there seems to be a change and it is probable that any large bombers built in the near future by the Army Air Corps will have more than one engine. The Navy recognizes some advantages in the multiple-engine arrangement and is investigating the possibility of its adaptation to meet the peculiar requirements of operation from shipboard. In commercial types the tendency is definitely toward a design using three engines.

Amphibian airplanes.—The further development of the amphibian airplane has been especially successful during the last year, and this type has now been adopted by the Army, Navy, and Coast Guard as a service airplane.

Differences between military and commercial types.—There is increased appreciation of the differences in the fundamentals of design of military and commercial types of airplanes. In the military types the design must be such as to enable the airplane to be catapulted, landed in an arresting gear, to carry bombs, torpedoes, and other armament, and in the lighter types to be highly maneuverable. This results in a structure which is highly specialized as compared with airplanes of commercial types.

Shock absorbers.—Shock absorbers of the hydraulic type have given such successful results in the landing gear of service airplanes that similar gear is being fitted to all service types. Future production orders will probably specify the use of this type of gear on all airplanes. This gear is also beginning to be used quite widely on commercial airplanes.

Brakes.—As a result of the successful development and use of brakes on the landing wheels of airplanes by the Army Air Corps, many commercial airplanes are now being fitted with wheel brakes. These are used not only to reduce the run after landing but also to increase the maneuverability of the airplane on the ground.

STRUCTURAL MATERIALS—*Metal construction.*—With the practically complete adoption of metal construction for the fuselage, attention has been transferred to the use of metal construction in the wings. Interest in this development is greatest in those cases where it appears possible to accomplish a saving in weight by the substitution of metal for wood. Extensive tests have been made on experimental metal wing beams by the engineering division, Air Corps, United States Army. Spars for these tests were designed by practically all of the important aircraft manufacturers.

It is particularly gratifying to note the extensive use of metal construction in many successful types of commercial aircraft developed in the last year. In addition to the metal fuselage, several manufacturers have introduced metal spars with metal ribs, others use metal spars and wooden ribs, while at least one manufacturer uses wooden spars with metal ribs. As a rule all-metal airplanes are original in design as well as in detail of construction, but one manufacturer has taken successful and standard types of military design in wood, or wood and metal, and reproduced them in all-metal construction.

Steel tubing.—Alloy steels, nickel and chrome molybdenum, are being used increasingly in place of mild steels for making the tubing used in welded fuselages. This type of fuselage is bound to profit from the race for improved welding methods which is now on. The new electrical methods in particular seem most promising of clean, high-strength welds.

Duralumin tubing.—Duralumin tubing also is superseding the mild-steel tubing. Manufacturers are successfully producing round and square tubing as well as structural shapes. They are being extensively used in the construction of fuselages and built-up spars.

Floats.—Metal construction has extended from the flying-boat hull to the smaller seaplane float of advanced design. Such floats have the double advantage of light weight to begin with and practical freedom from increase of weight caused by soakage while moored out. The uncertainty regarding the ability of duralumin to withstand corrosion, particularly under adverse circumstances, has retarded progress along these lines. With the development of a satisfactory method of protection against corrosion progress will certainly be accelerated.

Rubber "lumber."—An alternative material for metal, recently developed, is a variety of hard sponge rubber which is supplied in sheet form. This has been used in place of wood for the decks, bottoms, and bulkheads of floats of wooden type of construction. It is being employed in production orders and if as successful in service as preliminary tests indicate, it may replace wood very widely.

Rubber protective coatings.—A rubber coating which can be applied directly to wood and which is very difficult to remove has also been developed as a protection against soakage in the wooden floats. This appears to have possibilities, and in particular might be of use as a protection for existing wooden floats.

A rubber coating similar to that used for wood has also been applied to duralumin with a view to protecting it against corrosion. Service tests on both wood and metal floats protected in this manner are in progress.

AIRCRAFT ENGINES

Engines Available.—The present status of aircraft engine development is most satisfactory. In the water-cooled types we have proved engines of 200, 400, 500, 600, and 800 horsepower. In the air-cooled types we have highly developed engines of 200 and 400 horsepower. These engines meet most of our requirements. The air-cooled engines have been developed primarily for the Navy, which announced some time ago its policy of standardizing on air-cooled engines of three sizes—200, 400, and 500 horsepower. The 200-horsepower engine meets the needs of the primary training airplanes. The 400-horsepower engine is especially designed for high-performance aircraft, such as the observation and fighter types. The 500-horsepower engine is adapted to use in single or twin engined bombing, scouting, torpedo, and patrol airplanes. Upon the satisfactory completion of the 500-horsepower development, a line of three air-cooled engines will be available and new types of airplanes are being built around them to meet most of the needs of the Navy.

Principal Requirements.—The principal requirements for aircraft engines may be listed as follows: (1) Minimum weight per horsepower; (2) minimum fuel consumption; (3) maximum dependability; (4) maximum durability; (5) minimum first cost; (6) minimum maintenance cost. In so far as weight per horsepower is concerned, the new air-cooled radial engines weigh much less than 2 pounds per horsepower installed and ready to run as against more than 3 pounds per horsepower for the war-time Liberty engine. In so far as fuel economy is concerned, the new air-cooled radials show an improvement over the water-cooled engines.

In the matter of dependability, great strides have been made. Both the water-cooled and the air-cooled engines have been improved and refined to the point where only reasonable care is required to insure dependability of the engine itself. The chief difficulties are with gasoline, oil, and water systems, which do not always receive proper attention either in installation or maintenance.

The durability of aircraft engines is greatly increased. Many modern engines are running well over 300 hours without major overhaul, while the average life between such overhauls is at least twice that of earlier engines. The latest of the modern engines have been designed with particular reference to low first cost and low maintenance cost. The radial type air-cooled engine lends itself singularly well to this end.

In general, the aircraft engine situation is satisfactory from most viewpoints, and progress is being made. The developments so far are the result of excellent cooperation between the Army Air Corps, the Bureau of Aeronautics, and the industry. Thus in the development of the three sizes of air-cooled radial engines for the Navy, the industry has had a definite plan on which to work and has, under the guidance of the Navy Department, produced highly satisfactory engines. The 200-horsepower engine has already been widely adopted by the builders and operators of commercial aircraft. No doubt the other two types will prove of equal interest to the rapidly expanding commercial field. The 200-horsepower engine is now being redesigned from the standpoint of cost reduction, which should prove a further boon to commercial development.

AIRSHIPS

TECHNICAL DEVELOPMENT—*Present situation.*—The technical development of airships still lags behind that of airplanes. This may be expected to continue until airships are built in larger numbers and the correspondingly increased opportunities for the development of new ideas are available.

Aside from the erection of practically standardized small nonrigid airships by the Army and Navy, there has been no new airship construction begun in the United States. Experimental investigations and research have continued for the dual purpose of improving the existing airships and of providing improved materials and methods of construction for new airships when they are begun. Along this line considerable progress has been made. The corrosion of duralumin has been studied intensively and satisfactory methods for its protection are in sight. Satisfactory substitutes for the gold-beater's skin fabric used in earlier airships have been developed and are now being used in the construction of gas cells. Methods for the design of new girders of the Zeppelin type are being derived from tests of these girders. Continued study has been given to the development of methods for analyzing the distribution of loads in the structure of rigid airships, and such methods have been brought to better form.

Work with Los Angeles.—The *Los Angeles,* which has now been in the United States about two years, still remains a most useful and active airship and is regularly used in research on problems connected with the design and operation of rigid airships. A series of pressure-distribution experiments made simultaneously with the study of strain distribution has been carried out on this airship and the results generally conform to those obtained from the earlier experiments on the *C–7.* The measurement of pressures was confined primarily to the fins and rudders; and the measurement of strains, to the principal girders in certain selected locations. It was found that flying in rough air produced stresses much greater than those produced by maneuvering in still air. This airship was also used to determine by means of observations in a camera obscura the behavior of an airship while turning.

The operating personnel of the *Los Angeles* have been active in the development of improved methods for handling airships on the ground and in and out of the sheds and have developed apparatus which has already given good promise of success. They have also made modifications in the methods of mooring to the *Patoka,* which have reduced the time required for this maneuver very considerably below that which prevailed in the past.

The Navy has utilized the *Los Angeles* very effectively in the calibration of the inshore sectors of the various radiocompass stations along the Atlantic coast from Maine to North Carolina. In this work the airship has accomplished things which could not be done by any other means in such a short time. A notable operation was a flight to Detroit where the airship was moored to the new Ford mooring mast. This is the first time the mast was used for a rigid airship and the first time that a naval airship was moored to a privately owned mast.

Work with RS–1.—The large Army semirigid *RS–1* was completed early in the year and given a series of tests similar to those applied to the *Los Angeles* in order to determine the agreement between stresses in the structure of the keel as determined by computation and from model tests. The strain-gauge readings made in flights during April check the proportion of bending load carried by the keel with that indicated by computations and the model. The breathing stresses were found to be greater than computed. However, the stresses in the keel while in flight in rough weather were less than the breathing stresses alone.

This airship had the distinction of being the first airship to moor to the new Ford mooring mast. The operation was successful in every way.

Metal-clad airship.—An airship of novel design is under construction for the Navy Department by the Aircraft Development Corporation, of Detroit. In this design the flexible fabric envelope is replaced by a thin metal shell reinforced by transverse and longitudinal girders. Many novel constructions and new features are introduced in this design and its completion and tests will be watched with great interest.

New mooring masts.—A large mooring mast generally similar to the one at the naval air station, Lakehurst, N. J., has been completed at the Ford Airport, near Detroit, and, as noted, has been used by the *RS–1* and the *Los Angeles.* A second mooring mast differing radically from any previously constructed is being built at Scott Field, Belleville, Ill. In this case the mast is being designed as a circular tower of steel plate very much like a smokestack.

Helium.—Helium tank cars have been delivered to the Army and Navy. These cars have already shown the anticipated savings and the Army Air Corps has ordered a second car. There has been a disheartening fall in the production of helium owing to the exhaustion of the Petrolia gas field. New sources of supply will have to be found in the near future if the operation of airships with helium is to be continued.

Progress in Great Britain.—In spite of the progress noted above, the world leadership in the design and construction of rigid airships has passed from the United States to Europe. Great Britain now has under construction, after an extensive series of tests, two rigid airships each having a volume of not less than 5,000,000 cubic feet. One of the airships is built of members constructed of duralumin which are very similar to those used in the *Shenandoah* and the *Los Angeles.* The structure of the other is made of stainless steel. The construction of these two airships, practically sisters, will afford a very fine opportunity for the determination of the real merits of the two materials.

The beginning of final construction of these airships was preceded by a very thoroughgoing series of pressure-distribution tests made on the old British airship *R–33.* Results so far made available from these tests indicate that they gave very useful information to the designers. Full-size tests of sections of the structure to be used in these airships have also been made with very gratifying results.

Mooring masts having a structure of novel type have been erected at Ismailia, Egypt, as well as in Great Britain, while an airship shed has been built at Karachi, India. These masts have eight vertical members in place of three, as in the case of the Lakehurst and Ford masts.

Progress in Germany.—The limitation of the size of airships which might be built in Germany having been removed, that country is now engaged in the construction of a new rigid airship of about 3,500,000 cubic feet. This was originally proposed in connection with the flight to the North Pole and subscriptions to the amount of about one-half the cost were obtained for that purpose. Its completion is now being urged to demonstrate the practicability of transatlantic airship traffic.

An important development proposed for this new airship is carrying in special cells, comparable to ballonets, fuel gas instead of gasoline for use in the engines. The purpose is to increase the range and reduce the loss of buoyant gas during operation. This accomplishes the same end as the water-recovery apparatus used in America but with lighter weight. However, it introduces an inflammable gas which nullifies the advantages of helium. This development appears to have very good possibilities and will be followed with interest.

Progress in Italy.—The flight of the *Norge* from Rome across the North Pole was a triumph for the semirigid type of airship which has been under development for a number of years in Italy. The technical excellence of this type of airship could be demonstrated in no more striking form.

It is understood that the Italian Airship Works is preparing to construct a semirigid airship of 53,000 cubic meters volume, very nearly the size of the *Shenandoah,* which is to be ready in 1928. This airship is intended for flights to South America.

In further testimony of the high opinion which is held of the Italian semirigid airships, it is reported that Russia has purchased a semirigid airship of the same size as the *Norge* and that Japan has purchased two in succession. The second of these is to be erected very shortly.

AERONAUTICAL LEGISLATION AND GOVERNMENTAL ORGANIZATION

During the past year notable progress was made in clarifying the aeronautical atmosphere, which had been more or less beclouded for several years. The principal factor was the enactment by Congress of a program of constructive legislation based largely upon the recommendations of the President's Aircraft Board, of which Mr. Dwight W. Morrow was chairman, and the House Select Committee of Inquiry into Operations of the United States Air Services, of which Representative Florian Lampert was chairman. The reports of these two investigating bodies were made in November and December of 1925. The immediate effect was reflected in the enactment of:

1. The air commerce act (Public No. 254, 69th Cong.), approved May 20, 1926.
2. The Navy five-year aircraft program act (Public No. 422, 69th Cong.), approved June 24, 1926.
3. The Army five-year aircraft program act (Public No. 446, 69th Cong.), approved July 2, 1926.

Following is a brief analysis of the three measures referred to:

The Air Commerce Act.—The air commerce act represents the culmination of years of effort to secure legislation providing for the Federal regulation and encouragement of commercial aviation. It asserts for the first time in American history the doctrine of Federal sovereignty in the air space over the lands and waters of the United States to the exclusion of foreign nations, and the right of the Federal Government to regulate interstate air commerce and to prescribe air traffic rules governing private as well as commercial aircraft engaged in intrastate as well as interstate air navigation. It authorizes the Secretary of Commerce to establish airways, to light the same for night flying, to establish and maintain emergency landing fields, and leaves to the municipalities and to private industry the establishment and maintenance of airports. It provides for the Federal inspection and registration of aircraft, the examination and licensing of airmen, the furnishing of weather report service along airways, and the application of existing laws to foreign air commerce. It provides civil penalties for violations and makes the aircraft involved subject to liens for such penalties. It also authorizes the use of Government airports or landing fields by private citizens or corporations, and the furnishing of supplies and repairs in cases of necessity. It authorizes the transfer of the postal airways to the jurisdiction of the Secretary of Commerce and the transfer of the postal air terminals or airports to the municipalities concerned under arrangements subject to approval by the President. It creates an additional Assistant Secretary of Commerce for the sole purpose of assisting in the administration of the air commerce act.

Subsequently an appropriation of $250,000 was made for the administration of the act during the fiscal year 1927, and an additional appropriation of $300,000 for the furnishing of aids to air navigation along airways.

The Navy Five-Year Aircraft Program Act.—The Navy five-year aircraft program act provides legislative authority for the procurement over a period of five years of a total of not to exceed 1,614 airplanes for naval purposes at a cost, including spare parts and equipment, of not to exceed $85,078,750, and authorizes the annual procurement, after the fiscal year 1931, of not to exceed 333 airplanes, with spare parts and equipment, to cost not to exceed $17,476,250. It contemplates the constant maintenance of 1,000 useful airplanes in the naval service. The act provides legislative authority for the construction of two rigid airships of approximately 6,000,000-cubic-foot volume each at a total cost of not to exceed $8,000,000 for both, and also authorizes the purchase of an experimental metal-clad airship of approximately 200,000-cubic-foot volume at a cost of not to exceed $300,000.

The act clarifies the status of air personnel in the Navy and provides that Navy and Marine Corps air activities, including the operation of aircraft carriers and tenders, shall be commanded, respectively, by naval and Marine Corps flying personnel.

The act creates an additional Assistant Secretary of the Navy primarily to aid the Secretary of the Navy in fostering naval aeronautics.

The Army Five-Year Aircraft Program Act.—The Army five-year aircraft program act is a companion measure to the Navy five-year program act. It provides for the reorganization of the Army Air Service into an Air Corps and increases its strength to 1,650 officers and 15,000 enlisted men, authorizes the transfer to the Air Corps of officers of other branches of the Army, provides temporary advanced rank to commanding officers under certain limitations, provides for an investigation and study by the Secretary of War of alleged injustices in the promotion list of the Army and for the submission of recommendations to Congress to correct the same, creates for a period of three years an air section in each of the divisions of the General Staff, and clarifies the situation regarding flying pay.

The act authorizes a five-year air personnel expansion and aircraft procurement program, the latter being limited to the maintenance of 1,800 serviceable airplanes and such number of airships and free and captive balloons as may be necessary for training purposes.

The act creates an additional Assistant Secretary of War primarily to aid in fostering military aeronautics.

The act provides a method of procedure to be followed by the Army and the Navy in the procurement of aircraft, which involves design competitions and the recognition of proprietary rights for aircraft designs. The act creates a Patents and Design Board consisting of the Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce and provides that "to this board any individual, firm, or corporation may submit a design for aircraft, aircraft parts, or aeronautical accessories, and whether patented or unpatentable, the said board upon the recommendation of the National Advisory Committee for Aeronautics shall determine whether the use of such designs by the Government is desirable or necessary, and evaluate the designs so submitted and fix the worth to the United States of said design, not to exceed $75,000. The said designer, individual, firm, or corporation may then be offered the sum fixed by the board for the ownership or a nonexclusive right of the United States to the use of the design in aircraft, aircraft parts, or aeronautical accessories and upon the acceptance thereof shall execute complete assignment or nonexclusive license to the United States: *Provided*, That no sum in excess of $75,000 shall be paid for any one design."

The act further provides for the award of a soldier's medal and distinguished flying cross and certain increased emoluments for enlisted men of the Army who distinguish themselves in time of peace.

Contract Air-Mail Legislation.—The previous Congress had enacted an important measure known as the Kelly Act (Public No. 359, 68th Cong.), approved February 2, 1925, which authorized the Postmaster General to contract for air-mail service on a basis that promised successful commercial operation provided sufficient business could be secured. This measure led directly to the inauguration of contract air-mail service, which, in accordance with the Government's policy, will be increased until all air mail is carried under contracts and the Post Office Department is no longer engaged directly in the operation of aircraft. All air-mail contractors have not been successful financially, owing principally to lack of sufficient volume of business. The brief experience to date seems to indicate that contractors who depend for revenue on air mail alone can not succeed, and that they should extend their activities to include the transportation of passengers and goods.

Further Legislation Recommended.—To round out the program of constructive aeronautical legislation recently enacted into law, the National Advisory Committee for Aeronautics recommends further action by Congress along the following lines:

1. That the membership of the National Advisory Committee for Aeronautics be increased from 12 to 15 to provide for the appointment of the Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce. A bill to this effect (S. 4529) introduced by Senator Bingham passed the Senate at the last session of Congress, and a similar measure (H. R. 13115), introduced by Mr. James, was favorably reported to the House by the Committee on Military Affairs.
2. That the five-year aircraft construction programs of the Army and Navy approved at the last session of Congress be carried into effect.

In addition, there is the matter of "alleged injustices which exist in the promotion list of the Army," as to which Congress, in section 4 of the Army five-year aircraft program act, authorized the Secretary of War to make an investigation and study and to submit a report to the Congress.

The Present Government Aeronautical Organization.—In view of recent legislation, the committee deems it of timely interest to present briefly an outline of the present aeronautical organization of the Government:

1. Under the War Department there is an Army Air Corps functioning as a coordinate, combatant arm of the Army, with an authorized strength of 1,650 officers, 15,000 enlisted men, and 1,800 serviceable airplanes, and with an actual strength, as of June 30, 1926, of 919 officers, 8,720 enlisted men, and 1,254 serviceable airplanes, and under the immediate control of an Assistant Secretary of War for Aeronautics.

2. Under the Navy Department there is a Bureau of Aeronautics, functioning largely as a matériel bureau for the supply and development of naval aircraft and the training of flying personnel; a naval air organization serving as an integral part of the fleet, having no legal limitation on the number of personnel, but with an actual strength, as of October 1, 1926, of 715 officers and 3,600 enlisted men, and with an authorized complement of 1,000 serviceable airplanes, but a present strength of 639 serviceable airplanes; and with all aeronautical activities under the general cognizance of an Assistant Secretary of the Navy for Aeronautics.

3. Under the Department of Commerce, authority is vested in the Secretary of Commerce to regulate and encourage commercial aviation, with an Assistant Secretary of Commerce for Aeronautics in immediate charge of the work.

4. The National Advisory Committee for Aeronautics is the governmental agency that supervises and conducts scientific researches in aeronautics.

In addition to the above there are (*a*) the Air-Mail Service, the actual operation of which is gradually being turned over to private contractors; (*b*) the Weather Bureau, which has recently been authorized to furnish special weather report service along airways; (*c*) the Patents and Design Board, consisting of the Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce, to pass upon aeronautical inventions and designs submitted to the Government; and (*d*) the Aeronautical Board, composed of Army and Navy air officers, to effect coordination of military and naval air plans.

COMMERCIAL AVIATION

With the enactment of the air commerce act of 1926, the Congress has laid the legislative corner stone for the development of civil and commercial aviation in America on a practical basis. Under this act the Secretary of Commerce will establish airways and emergency landing fields, inspect and register aircraft and facilities, and examine and license airmen. He will encourage the establishment of airports, recommend the necessary meteorological service to be provided by the Weather Bureau, study the possibilities for the development of air commerce and disseminate information relative thereto, provide for the development of air navigation facilities, investigate and report upon causes of accidents in civil air navigation, and in general foster the development of air commerce. A significant feature of the law is that the establishment of airports or air terminals is left to the municipalities or to private industry, the Federal Government providing the connecting airways and facilities between terminals.

The act is comprehensive in scope and meets a fundamental need that has been the subject of annual recommendations of the committee for several years past. The committee does not propose to report on commercial aviation as such, as this matter, in accordance with the air commerce act, will be dealt with in the future by the Secretary of Commerce. The committee wishes at this time to record its gratification with the enactment of this legislation and to express its belief that it is fundamentally sound, and will, without direct subsidies, lead to the development of commercial aviation in America on a sound basis.

AERONAUTICAL RESEARCH IN THE UNITED STATES

Under the law the supervision and direction of the scientific study of the problems of flight are intrusted to the National Advisory Committee for Aeronautics, which is also authorized to conduct researches in its own laboratories provided by governmental appropriations, and in any other laboratories which may be placed at its disposal. The committee is composed in part of representatives of governmental agencies concerned with the use of aeronautics—namely, the Army and Navy air organizations; of certain governmental scientific agencies interested in aeronautical problems—namely, the Smithsonian Institution, the Weather Bureau, and the Bureau of Standards; and of members appointed from private life. These latter, five in number, are not connected with aeronautics as a business but are men of science who have been appointed by the President because of their knowledge of aeronautical science. Membership on the committee is, therefore, both an honor, being a recognition of scientific ability, and an opportunity for patriotic service. It has never been refused by anyone who has been invited to serve either as a member of the main committee or on one of its subcommittees.

Because of this feature of its organization, the committee is able to obtain the services of men eminent in science, whose services on a compensation basis would be practically unobtainable. This applies equally to the subcommittees, which are organized along much the same lines as the main committee and which are composed of technical representatives of the Army and Navy air organizations, and civilian experts appointed from private life. Through the committee and its subcommittees the research activities of the country are coordinated and guided for the purpose of advancing the science of aeronautics in America.

Aeronautical research in the United States is supported by the Government both for the purpose of advancing the science and art of aeronautics as such, and because of the recognition of the direct bearing of aeronautical development upon national defense.

Each year shows improvements in the performance of aircraft, and consequently the relative military importance of aviation in war increases. Because of this continuous development, it has become more and more desirable to achieve and maintain leadership.

Leadership in the operation of commercial air lines will probably remain in European hands for some years, owing to the European policies of direct subsidies. Ultimate leadership will depend upon the solution of the basic problems of reduced cost and greater safety. These problems will be most effectively met through the encouragement and support of a comprehensive program of aeronautical research.

For ultimate leadership in the development of aeronautics, whether for military purposes or for commercial purposes, the United States depends primarily on the results of continuous research and development. The National Advisory Committee for Aeronautics therefore believes it to be its duty to emphasize the importance of scientific research as the most fundamental activity of the Government in connection with the development of aeronautics.

Aeronautical research programs are initiated by the various technical subcommittees as a result of frequent meetings and discussions of the need for development in their respective spheres. The research programs usually indicate the laboratory, public or private, in which each investigation recommended can be conducted to the best advantage. The executive committee considers the recommendations of the various subcommittees, determines the investigations to be undertaken, and allots funds when necessary.

The more fundamental investigations are undertaken by the committee in its own laboratory known as the Langley Memorial Aeronautical Laboratory, located at Langley Field, Va., on a plot of ground set aside for the purpose by the War Department and on which necessary buildings and equipment have been erected by the committee from appropriations made by the Congress. Special investigations for which adequate facilities are available elsewhere are referred to other organizations, such as the Army and Navy air organizations, the Bureau of Standards, the Weather Bureau, the Forest Products Laboratory, and educational institutions.

In the allocation of problems, the executive committee is guided by two main purposes: First, to have each investigation undertaken by an organization having proper equipment and personnel to handle the problem expeditiously and economically; and second, to distribute problems to educational institutions in such a manner as to encourage the development of trained investigators in the field of aeronautical science.

In this connection, as well as along other lines, the Daniel Guggenheim Fund for the Promotion of Aeronautics promises to be of much help, as it has made allotments of funds to universities to provide needed equipment and to maintain facilities for instruction of students in aeronautics. There is close cooperation between the committee and the management of the Guggenhein fund. Two members of the committee, Dr. W. F. Durand, a past chairman, and Mr. Orville Wright, are also members of the Guggenheim fund.

It is evident from the statement of the governing principles of the Guggenheim fund and the caliber of its personnel that its activities will be carefully planned to produce a maximum of beneficial results and at the same time will avoid duplication with existing agencies, governmental and private.

The aeronautical research work of the committee does not relate exclusively to the development of military and naval aircraft but also includes the fundamental problems in aeronautics which relate to commercial aviation. The committee's organization for the conduct of aeronautical research as described is such as to enable it to work effectively with such agencies as the Guggenheim fund, as well as with educational institutions and the other governmental agencies concerned. This makes it possible to obtain results with a maximum of economy and efficiency.

The fundamental factors which have made for the success of the committee may be briefly stated as follows:

1. Its members serve without compensation, which enables the Government to obtain the services of men who would not otherwise be available for Government service.

2. The committee reports direct to the President and receives its appropriations direct from the Congress and by virtue of its status is enabled to initiate and conduct investigations of a truly scientific character, limited only by the funds available.

3. The research laboratories of the committee are located on an adequate flying field where all phases of the work, including the flight operations involved, are controlled and actually performed by the committee's own technical staff, thus bringing theory and practice together under ideal conditions.

4. The committee has the confidence and support of the Army and the Navy air organizations and is able at all times to obtain any cooperation desired.

SUMMARY

Progress in technical development has been continuous and has been reflected in improved performance of aircraft for both military and commercial purposes. In the matter of technical development for military purposes America has fully kept pace with foreign developments. The commercial use of airplanes is much further developed in Europe than in America. There large airplanes have been extensively developed for commerical and passenger-carrying services. This has been made possible largely by reason of direct governmental subsidies. In America since the war there have been intermittent attempts to establish passenger-carrying services. These have usually not been financially successful. Aviation in the United States must largely pay its own way, the Government merely doing what it should properly do in the way of establishing and maintaining airways and otherwise encouraging the development of commercial aviation without resorting to the European policy of direct subsidies.

Before commercial aviation can be extensively developed in the United States on a self-supporting basis, there must be substantial reductions in cost of construction, maintenance, and operation of aircraft, and substantial improvement in the safety of aerial navigation. For military purposes the problems are not so acute but are basically the same. The probability is remote that a revolutionary principle will be discovered that will contribute any great or sudden improvement to aircraft. It follows that the development of aviation will be limited to a gradual progress from year to year that is based largely on the fruits of scientific study and investigation of the basic problems of flight. This is the prescribed function of the National Advisory Committee for Aeronautics and in the last analysis is necessarily the most fundamental activity of the Government in connection with the development of aeronautics for civil and military purposes. The fact is emphasized that the problems which confront us are greater safety and lower cost of structure.

The enactment by Congress in 1926 of a constructive program of aeronautical legislation affecting military, naval, and commercial aviation in America promises great improvement in the aeronautical situation from the point of view of organization, personnel, and matériel. The creation by Congress of an aeronautical Patents and Design Board, consisting of assistant secretaries for aeronautics in the Departments of War, Navy, and Commerce, takes care of the problem of considering aeronautical inventions offered to the Government. The enactment of the air commerce act gives an important measure of stability to commercial aviation as a business proposition and in its direct effects will go far toward encouraging the development of civil and commercial aviation. The condition of the aircraft industry has continued to improve and the enactment into law of five-year aircraft building programs for the Army and the Navy, when carried into effect, will assure sufficient Government business to maintain a healthy nucleus of an aircraft industry that in time should find its principal support in meeting the needs of commercial aviation.

A BRIGHT OUTLOOK.—With the governmental agencies organized on a sound and logical basis and functioning in cooperation; with the regulation of commercial aviation under Federal supervision; with the impetus given to aeronautical education by the Daniel Guggenheim Fund for the Promotion of Aeronautics; with the continuous development of military and naval aeronautics assured under the approved five-year programs of the Army and Navy; and with the aircraft industry in a healthy condition, we have, for the first time in our history, a well-rounded aeronautical organization in the Government and a bright outlook for the advancement of aeronautics, civil and military. With the concerted effort of all the agencies concerned, governmental and private, we can reasonably expect greater progress than we have had in the past. There remain, however, the fundamental problems of increasing the safety and economy of aircraft and of interesting the people in their use and in the establishment by the municipalities or by private industry of their own airports and air terminal facilities. Federal pressure can not properly be exerted in this direction, but it is thought that those private organizations which concern themselves with the civic, national, and scientific development of the country have a field of great potential usefulness in educating the business men of every city as to the need for airports and in educating the public generally as to the possibilities of aviation as a means of transportation and of pleasure that is destined ultimately to prove as revolutionary in the economic life of the Nation as was the development of the automobile.

CONCLUSION

America leads the world in the private ownership and operation of aircraft; is at least abreast of other progressive nations in the technical development of aircraft for military purposes; and has the technical knowledge necessary to equal or excel the commercial airplanes of other nations. It is the opinion of the National Advisory Committee for Aeronautics that, without following the European policy of direct subsidies, American commercial aviation will surpass European developments when, but not until, the construction and operation of aircraft can meet the economic demands of lower cost and greater safety. Gradual improvement along these lines would result from trial-and-error methods, but substantial and rapid progress will necessitate, and depend mainly upon, the continuous prosecution of scientific research on the fundamental problems of flight.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
JOSEPH S. AMES, *Chairman Executive Committee.*

REPORT No. 233

THE AERODYNAMIC CHARACTERISTICS OF SEVEN FREQUENTLY USED WING SECTIONS AT FULL REYNOLDS NUMBER

By MAX M. MUNK and ELTON W. MILLER
Langley Memorial Aeronautical Laboratory

REPORT No. 233

THE AERODYNAMIC CHARACTERISTICS OF SEVEN FREQUENTLY USED WING SECTIONS AT FULL REYNOLDS NUMBER

By Max M. Munk and Elton W. Miller

SUMMARY

This report contains the aerodynamic properties of the wing sections U. S. A. 5, U. S. A. 27, U. S. A. 35 A, U. S. A. 35 B, Clark Y, R. A. F. 15, and Göttingen 387, as determined at various Reynolds Numbers up to an approximately full scale value in the variable density wind tunnel of the National Advisory Committee for Aeronautics.

It is shown that the characteristics of the wings investigated are affected greatly and in a somewhat erratic manner by variation of the Reynolds Number. In general there is a small increase in maximum lift and an appreciable decrease in drag at all lifts.

INTRODUCTION

The tests described in this report were made in the variable density wind tunnel of the National Advisory Committee for Aeronautics. The construction of this tunnel, the features particular to it, and the reasons for providing such features will be the subject of another report.

Since the effective linear model size is equal to the actual model size multiplied by the ratio of the test density to the normal density of air, full scale values of the Reynolds Number are obtained in the variable density wind tunnel with moderate wind speeds on models of ordinary size by compressing the air to about twenty times its normal density (or normal pressure).

The present tests are among the first made in the variable density wind tunnel, and, as might be expected from the newness of the work, there are certain runs and individual readings which do not appear to check with the remaining data. Owing to the general interest in these data and their probable value to airplane designers, it has been decided to make the data immediately available in the present form and to give more complete and more accurate data in some future report or reports. The general effect of the Reynolds Number and the characteristics of the various airfoils at large Reynolds Number are considered to be given with reasonable accuracy by these data.

METHOD OF TEST

The models were smoothly cut of duralumin in rectangular form, 30-inch span and 5-inch chord, with equal and parallel sections along the span. The span of the models, 30-inches, is one-half of the throat diameter of the wind tunnel. In the tests each model was fastened to the tunnel balance by means of thin wires and a vertical shielded bar extending across the tunnel in rear of the model. A skid rigidly connected with the model was hinged to this bar, so that the angle of attack could be changed during the tests by moving the bar up or down.

Each model was investigated through a range of angles of attack at an approximately constant pressure of the air circulating in the wind tunnel. This pressure was increased in steps and each time the test repeated.

In the same way the resistance of the wires and of other auxiliary parts was determined. This latter test includes the slight forces exerted by the air flow on the balances directly, in consequence of small leakages between the test room, the balance room, and the return channel.

The corrections found were applied to the readings obtained with the model at various angles of attack and at various pressures. The velocity of the air flow is approximately the same in all tests, with an average value of about 76 feet per second.

RESULTS OF THE TESTS

The results of the tests are given in the tables and diagrams of this report. Table XXXVI gives the exact shape of the wing sections tested, the ordinates being obtained by measuring the finished model. It is worth mentioning in this connection that in several cases no strict specification of the section exists, as, for instance, several tables of ordinates for the R. A. F. 15 published at different times differ from each other. In such cases the ordinates in general use have been adopted.

Tables I to XXXV give the lift coefficient, drag coefficient, and some of them the moment coefficient for a series of angles of attack, each table for an approximately constant dynamic pressure. The lift coefficient C_L and drag coefficient C_D are obtained by dividing the measured lift L and the corrected drag D by the wing area S and by the dynamic pressure q.

$$C_L=\frac{L}{qS} \text{ and } C_D=\frac{D}{qS}$$

where

$$q=\frac{1}{2}\rho V^2$$

The velocity is always about 76 feet per second. The moment coefficient C_M is obtained from the moment measured with respect to the point on the chord one-quarter chord length from the leading edge, by dividing it by the wing area, by the chord c and by the dynamic pressure q.

$$C_M=\frac{M}{qcS}$$

C_M is positive if it tends to increase the angle of attack; that is, to lift the leading edge up and turn the trailing edge down. The average Reynolds Number for each test is also inserted. The Reynolds Number is computed with reference to the chord as characteristic length of the model.

The results are illustrated by diagrams in the form of the so-called polar curves. There are two diagrams for each section. The one refers to the test at about 20-atmosphere tank pressure, which can be considered as equivalent to a full-size test for an airplane of moderate size. This diagram contains a profile of the section. The lift coefficient is plotted vertically, and against it to the right are plotted the induced drag coefficient (giving a parabola), the observed drag coefficient (giving the polar curve proper), and the negative moment coefficient.

In a second diagram all polar curves of one section observed at different pressures, and hence at different Reynolds Numbers, are drawn side by side. The parabola of induced drag is inserted again.

It appears that the polar curves obtained at different Reynolds Numbers differ appreciably from each other, particularly with the thicker sections. The drag coefficient has generally the tendency to decrease with increase of Reynolds Number, while the lift is not very much affected except in the neighborhood of its maximum.

Table XXXVII has been prepared by Lieut. Walter S. Diehl to supply a condensed summary of the test data in the form commonly used for study of comparative tests. It should be noted that these data are not comparative with tests conducted on other models in other wind tunnels unless appropriate corrections are applied.

CONCLUSIONS

While only conclusions of the most general nature can be safely drawn from these tests, there are certain outstanding features, as follows:

(1) At any given lift coefficient the drag coefficient has a tendency to decrease as the Reynolds Number is increased.

(2) The greater the value of minimum drag coefficient at one atmosphere the greater the decrease in minimum drag with increase in Reynolds Number. This is true whether the decrease be taken as an absolute value or as a ratio. In this connection Lieut. Walter S. Diehl points out that the absolute decrease in minimum drag coefficient in passing from 1 to 20 atmospheres for the seven airfoils of this report varies approximately as the cube of the minimum drag coefficient at 1 atmosphere. This relation is probably accidental and is merely cited to show the general nature of the variation.

(3) Except in the neighborhood of the maximum, the lift coefficient does not appear to be influenced by change in Reynolds Number.

(4) The maximum lift coefficient is very much affected by change in Reynolds Number. The effect on maximum lift coefficient is quite erratic, and in passing from 1 atmosphere to 20 atmospheres varies from an increase of 14 per cent to a decrease of 23.4 per cent.

Since there is no known reason for doubting that the variations obtained in airfoil characteristics at the higher pressures are a direct effect of the variation in Reynolds Number, it is believed that the aerodynamical properties obtained from tests made in the variable density wind tunnel at full scale values of the Reynolds Number are more reliable and more directly applicable to design than similar data obtained in the ordinary atmospheric wind tunnels at the usual low values of Reynolds Number. This conclusion is supported by the fact that at a pressure of 1 atmosphere the variable density wind tunnel gives results which are in very good agreement with those obtained in the conventional atmospheric wind tunnels.

TABLE I

[Airfoil section U. S. A. 5; model No. 15; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m²; aspect ratio 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m²	C_L	C_D
−6.0	28.1	−0.151	0.0599
−4.5	28.0	.000	.0382
−3.0	28.0	.141	.0204
−1.5	28.0	.254	.0142
0.0	28.0	.354	.0152
1.5	28.1	.489	.0197
3.0	28.1	.587	.0263
4.5	28.1	.694	.0341
6.0	28.1	.808	.0437
9.0	28.0	1.011	.0648
12.0	28.0	1.111	.0945
15.0	28.0	1.111	.1421
18.0	28.0	1.144	.2739
21.0	27.8	1.051	.3650

Average temperature 23° C.; average tank pressure, 1 atmosphere; average Reynolds Number, 179,000.

TABLE II

[Airfoil section, U. S. A. 5; model No. 15; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m², aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m²	C_L	C_D
−6.0	76.1	−0.116	0.0573
−4.5	76.1	.011	.0401
−3.0	76.1	.132	.0202
−1.5	75.7	.250	.0140
0.0	76.8	.365	.0147
1.5	76.1	.483	.0200
3.0	75.7	.593	.0263
4.5	75.4	.697	.0333
6.0	75.6	.811	.0424
9.0	76.1	1.007	.0667
12.0	76.1	1.127	.0955
15.0	77.0	1.202	.1402
18.0	76.1	1.165	.2667
21.0	75.4	1.058	.3642

Average temperature, 20° C.; average tank pressure, 2.62 atmospheres; average Reynolds Number, 482,000.

TABLE III

[Airfoil section, U. S. A. 5; model No. 15; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−6.0	140.0	−0.126	0.0588
−4.5	140.0	−.025	.0402
−3.0	140.0	.133	.0225
−1.5	139.8	.243	.0143
0.0	139.8	.359	.0157
1.5	139.8	.474	.0203
3.0	139.7	.585	.0264
4.5	139.7	.688	.0336
6.0	139.5	.810	.0424
9.0	139.5	1.000	.0668
12.0	139.5	1.134	.0945
15.0	139.5	1.214	.1402
18.0	136.3	1.168	.2623
21.0	137.6	1.065	.3633

Average temperature, 26° C.; average tank pressure, 4.86 atmospheres; average Reynolds Number, 863,000.

TABLE IV

[Airfoil section, U. S. A. 5; model No. 15; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−6.0	310	−0.131	0.0589
−4.5	311	−.025	.0406
−3.0	312	.127	.0213
−1.5	312	.234	.0124
0.0	312	.351	.0148
1.5	312	.467	.0193
3.0	313	.582	.0259
4.5	313	.688	.0336
6.0	310	.806	.0418
9.0	310	1.010	.0643
12.0	310	1.159	.0958
15.0	310	1.188	.1381
18.0	307	1.151	.2440
21.0	300	1.092	.3580

Average temperature, 33° C.; average tank pressure, 10.48 atmospheres; average Reynolds Number, 1,840,000.

TABLE V

[Airfoil section, U. S. A. 5; model No. 15; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient	Moment coefficient [1]
Degrees	q, kg/m^2	C_L	C_D	C_M
−6.0	633	−0.133	0.0586	−0.071
−4.5	635	−.030	.0388	−.012
−3.0	639	.101	.0142	−.059
−1.5	645	.237	.0115	−.093
0.0	640	.324	.0144	−.094
1.5	639	.441	.0180	−.092
3.0	634	.562	.0244	−.095
4.5	643	.662	.0310	−.110
6.0	643	.782	.0400	−.098
9.0	642	1.001	.0629	−.080
12.0	641	1.188	.0918	−.078
15.0	640	1,184	.1250	−.122
18.0	626	1.134	.2163	−.121
21.0	621	1.080	.3173	−.154

[1] Moments taken about a point at 25 per cent of the chord.

Average temperature, 35° C.; average tank pressure, 20.07 atmospheres; average Reynolds Number, 3,630,000.

TABLE VI

[Airfoil section, U. S. A. 27; model No. 16; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−6.0	27.1	−0.046	0.0484
−4.5	27.1	.072	.0276
−3.0	27.1	.190	.0177
−1.5	27.1	.282	.0188
0.0	27.1	.392	.0194
1.5	26.8	.494	.0247
3.0	26.8	.628	.0297
4.5	27.2	.728	.0396
6.0	27.2	.830	.0471
9.0	27.2	1.015	.0688
12.0	27.2	1.198	.0947
15.0	27.2	1.304	.1228
18.0	27.1	1.270	.1891
21.0	26.9	1.142	.2552

Average temperature, 23° C; average tank pressure, 1 atmosphere; average Reynolds Number, 175,000.

TABLE VII

[Airfoil section, U. S. A. 27; model No. 16; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−6.0	73.3	−0.041	0.0469
−4.5	73.3	.062	.0265
−3.0	73.6	.168	.0171
−1.5	73.6	.260	.0149
0.0	73.6	.367	.0176
1.5	73.6	.474	.0218
3.0	72.5	.579	.0269
4.5	72.5	.678	.0330
6.0	72.5	.788	.0417
9.0	72.5	.989	.0649
12.0	72.5	1.165	.0869
15.0	72.5	1.214	.1304
18.0	71.8	1.167	.1915
21.0	71.8	1.154	.2410

Average temperature, 26° C.; average tank pressure, 2.58 atmospheres; average Reynolds Number, 456,000.

TABLE VIII

[Airfoil section, U. S. A. 27; model No. 16; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−6.0	148	−0.058	0.0441
−4.5	148	.045	.0253
−3.0	148	.153	.0144
−1.5	148	.248	.0131
0.0	148	.361	.0159
1.5	148	.470	.0203
3.0	148	.578	.0251
4.5	148	.686	.0322
6.0	148	.795	.0408
9.0	148	.999	.0606
12.0	148	1.163	.0852
15.0	148	1.206	.1293
18.0	146	1.168	.1991
21.0	146	1.076	.2529

Average temperature, 29° C.; average tank pressure, 5.10 atmospheres; average Reynolds Number, 900,000.

TABLE IX

[Airfoil section, U. S. A. 27; model No. 16; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−6.0	318	−0.044	0.0307
−4.5	318	.031	.0170
−3.0	318	.131	.0119
−1.5	318	.234	.0130
0.0	318	.345	.0160
1.5	318	.455	.0203
3.0	320	.560	.0259
4.5	320	.659	.0328
6.0	320	.771	.0407
9.0	320	.966	.0602
12.0	319	1.148	.0857
15.0	316	1.290	.1160
18.0	316	1.246	.1848
21.0	313	1.140	.2533

Average temperature, 25° C.; average tank pressure, 10.14 atmospheres; average Reynolds Number, 1,890,000.

TABLE X

[Airfoil section, U.S.A. 27; model No., 16; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient	Moment coefficient [1]
Degrees	q, kg/m^2	C_L	C_D	C_M
−6.0	624	−0.100	0.0127	−0.086
−4.5	626	.007	.0117	−.088
−3.0	626	.120	.0117	−.082
−1.5	625	.221	.0131	−.082
0.0	626	.332	.0160	−.081
1.5	626	.439	.0198	−.073
3.0	627	.553	.0255	−.061
4.5	628	.654	.0325	−.074
6.0	627	.768	.0417	−.064
9.0	626	.972	.0616	−.064
12.0	629	1.165	.0863	−.052
15.0	629	1.326	.1169	−.056
16.0	625	1.386	.129	−.161
18.0	627	1.324	.1815	−.154
21.0	613	1.181	.262	−.192

[1] Moments taken about a point at 25 per cent of the chord.

Average temperature, 34°C.; average tank pressure 19.92 atmospheres; average Reynolds Number, 3,570,000.

TABLE XI

[Airfoil section U. S. A. 35 A; model No., 17; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−9.0	28.2	0.019	0.0776
−6.0	28.1	.197	.0227
−4.5	27.9	.300	.0230
−3.0	27.9	.410	.0249
−1.5	27.9	.510	.0281
0.0	27.9	.640	.0359
1.5	27.9	.740	.0428
3.0	27.9	.860	.0519
4.5	27.9	.960	.0615
6.0	27.9	1.070	.0740
9.0	27.9	1.263	.0990
12.0	27.9	1.410	.1280
15.0	27.9	1.520	.1630
18.0	27.9	1.570	.2110
21.0	27.9	1.570	.2610

Average temperature 20° C.; average tank pressure, 1 atmosphere; average Reynolds Number, 180,000.

TABLE XII

[Airfoil section, U. S. A. 35 A; model No., 17; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−9.0	72.4	0.003	0.0612
−6.0	72.6	.200	.0190
−4.5	72.9	.298	.0202
−3.0	72.5	.408	.0234
−1.5	71.8	.515	.0281
0.0	71.8	.629	.0337
1.5	71.8	.739	.0414
3.0	71.8	.844	.0491
4.5	71.8	.945	.0600
6.0	71.8	1.047	.0701
9.0	71.8	1.213	.0950
12.0	71.3	1.359	.1253
15.0	71.3	1.445	.1670
18.0	71.3	1.486	.3620
21.0	71.1	1.480	.4110

Average temperature, 22° C.; average tank pressure, 2.48 atmospheres; average Reynolds Number, 450,000.

TABLE XIII

[Airfoil section, U. S. A. 35 A; model No., 17: span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−9.0	156.3	−0.045	0.0150
−6.0	156.3	.186	.0149
−4.5	156.3	.290	.0171
−3.0	157.1	.409	.0215
−1.5	158.0	.513	.0258
0.0	158.0	.626	.0319
1.5	155.5	.731	.0401
3.0	155.5	.838	.0479
4.5	155.5	.936	.0581
6.0	155.5	1.041	.0696
9.0	155.5	1.215	.0953
12.0	156.3	1.363	.1303
15.0	155.0	1.412	.1721
18.0	155.0	1.434	.2320
21.0	154.0	1.424	.2790

Average temperature, 25° C.; average tank pressure, 5.37 atmospheres; average Reynolds Number, 960,000.

TABLE XIV

[Airfoil section, U. S. A. 35 A; model No., 17; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−9.0	317	−0.058	0.0181
−6.0	315	.173	.0150
−4.5	318	.269	.0166
−3.0	319	.387	.0206
−1.5	311	.491	.0247
0.0	313	.602	.0313
1.5	313	.709	.0391
3.0	310	.806	.0460
4.5	310	.901	.0565
6.0	309	.989	.0676
9.0	304	1.162	.1042
12.0	304	1.225	.1480
15.0	310	1.240	.1848
18.0	309	1.205	.2400
21.0	304	1.131	.2847

Average temperature, 27° C.; average tank pressure, 10.25 atmospheres; average Reynolds Number, 1,860,000.

TABLE XV

[Airfoil section, U. S. A. 35 A; model No., 17; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m²; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient	Moment coefficient[1]
Degrees	p, kg/m²	C_L	C_D	C_M
−9.0	629	−0.075	0.0168	−0.117
−6.0	637	.146	.0142	−.118
−4.5	636	.252	.0162	−.116
−3.0	632	.365	.0196	−.112
−1.5	630	.468	.0240	−.107
0.0	612	.586	.0304	−.108
1.5	617	.692	.0378	−.107
3.0	617	.798	.0468	−.104
4.5	631	.884	.0564	−.101
6.0	631	.984	.0677	−.110
9.0	630	1.142	.0956	−.105
12.0	627	1.203	.1399	−.127
15.0	615	1.201	.1934	−.142
18.0	617	1.152	.2424	−.150
21.0	616	1.097	.2877	−.123

[1] Moments taken about a point at 25 per cent of the chord.

Average temperature, 40° C.; average tank pressure, 20.3 atmospheres; average Reynolds Number, 3,520,000.

TABLE XVI

[Airfoil section, U. S. A. 35 B; model No., 18; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m²; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m²	C_L	C_D
−9.0	24.9	−0.257	0.1096
−6.0	25.0	−.021	.0260
−4.5	25.2	.082	.0214
−3.0	25.2	.185	.0207
−1.5	25.2	.291	.0227
0.0	25.2	.401	.0264
1.5	25.2	.520	.0314
3.0	25.2	.640	.0395
4.5	25.2	.753	.0473
6.0	25.2	.865	.0589
9.0	25.2	1.060	.0847
12.0	25.2	1.218	.1125
15.0	25.2	1.245	.1525
18.0	25.0	1.150	.2566
21.0	25.0	.930	.3572

Average temperature, 32° C.; average tank pressure, 1 atmosphere; average Reynolds Number, 163,000.

TABLE XVII

[Airfoil section, U. S. A. 35 B; model No., 18; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0958 m²; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m²	C_L	C_D
−9.0	65.6	−0.245	0.0675
−6.0	65.6	−.033	.0148
−4.5	65.6	.073	.0141
−3.0	65.6	.186	.0149
−1.5	65.7	.292	.0185
0.0	65.5	.410	.0215
1.5	65.0	.526	.0279
3.0	65.5	.627	.0332
4.5	65.0	.736	.0431
6.0	65.0	.852	.0535
9.0	65.5	1.053	.0794
12.0	65.5	1.211	.1077
15.0	64.3	1.253	.1561
18.0	64.3	1.212	.2151
21.0	64.3	1.083	.3187

Average temperature, 28° C.; average tank pressure, 2.45 atmospheres; average Reynolds Number, 415,000.

TABLE XVIII

[Airfoil section, U. S. A. 35 B; model No., 18; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m²; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m²	C_L	C_D
−9.0	146.4	−0.260	0.0359
−6.0	145.6	−.036	.0111
−4.5	145.6	.069	.0115
−3.0	145.4	.180	.0123
−1.5	145.4	.288	.0150
0.0	145.4	.408	.0204
1.5	144.5	.524	.0264
3.0	144.3	.690	.0336
6.0	146.0	.852	.0529
9.0	146.0	1.054	.0782
12.0	146.0	1.221	.1060
15.0	146.0	1.301	.1518
18.0	146.0	1.232	.2210
21.0	144.2	1.196	.2827

Average temperature, 41° C.; average tank pressure, 5.24 atmospheres; average Reynolds Number, 859,000.

TABLE XIX

[Airfoil section, U. S. A. 35 B; model No., 18; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m²; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m²	C_L	C_D
−9.0	289	−0.278	0.0168
−6.0	290	−.053	.0103
−4.5	290	.054	.0101
−3.0	290	.169	.0125
−1.5	290	.280	.0144
0.0	290	.397	.0191
1.5	290	.510	.0256
3.0	290	.625	.0335
6.0	290	.845	.0504
9.0	289	1.050	.0760
12.0	289	1.240	.1049
15.0	289	1.370	.1411
18.0	289	1.327	.2144
21.0	289	1.167	.2805

Average temperature, 40° C.; average tank pressure, 10.2 atmospheres; average Reynolds Number, 1,695,000.

TABLE XX

[Airfoil section, U. S. A. 35 B; model No., 18; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m²; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient	Moment coefficient[1]
Degrees	q, kg/m²	C_L	C_D	C_M
−9.0	620	−0.285	0.0168	−0.072
−6.0	628	−.062	.0094	−.074
−4.5	623	.044	.0093	−.071
−3.0	623	.157	.0107	−.070
−1.5	618	.263	.0138	−.070
0.0	624	.378	.0174	−.052
1.5	624	.488	.0231	−.054
3.0	624	.603	.0308	−.061
6.0	623	.823	.0497	−.054
9.0	622	1.045	.0746	−.059
12.0	621	1.235	.1030	−.064
15.0	621	1.374	.1365	−.099
18.0	617	1.304	.2149	−.096
21.0	616	1.181	.2965	−.152

[1] Moments taken about a point at 25 per cent of the chord.

Average temperature, 40° C.; average tank pressure, 19.82 atmospheres; average Reynolds Number, 3,470,000.

TABLE XXI

[Airfoil section, Clark Y; model No., 14; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−6.0	28.1	−0.007	0.0150
−4.5	28.1	.096	.0127
−3.0	28.1	.210	.0131
−1.5	28.1	.306	.0141
0.0	28.1	.421	.0168
1.5	28.1	.545	.0223
3.0	28.1	.637	.0293
4.5	28.1	.744	.0372
6.0	28.1	.858	.0478
9.0	28.4	1.060	.0703
12.0	28.4	1.199	.0940
15.0	28.4	1.208	.1420
18.0	28.4	1.133	.2389
21.0	27.9	.908	.3629

Average temperature, 16° C.; average tank pressure, 1 atmosphere; average Reynolds Number, 181,000.

TABLE XXII

[Airfoil section, Clark Y; model No., 14; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−6.0	72.2	−0.029	0.0114
−4.5	72.2	.080	.0105
−3.0	72.0	.193	.0113
−1.5	71.1	.299	.0145
0.0	72.2	.417	.0176
1.5	72.2	.516	.0225
3.0	71.2	.618	.0275
4.5	72.0	.725	.0369
6.0	72.0	.836	.0570
9.0	72.0	1.037	.0795
12.0	72.0	1.168	.1072
15.0	71.2	1.182	.1476
18.0	71.2	1.118	.2124
21.0	71.2	.970	.2545

Average temperature, 19.5° C.; average tank pressure, 2.52 atmospheres; average Reynolds Number, 460,000.

TABLE XXIII

[Airfoil section, Clark Y; model No., 14; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−6.0	156	−0.040	0.0102
−4.5	157	.073	.0097
−3.0	155	.179	.0108
−1.5	155	.293	.0131
0.0	155	.403	.0169
1.5	155	.510	.0220
3.0	155	.620	.0290
4.5	154	.725	.0370
6.0	154	.839	.0471
9.0	154	1.025	.0693
12.0	153	1.184	.0966
15.0	153	1.188	.1461
18.0	152	1.126	.2251
21.0	152	1.042	.3045

Average temperature, 27° C.; average tank pressure, 5.44 atmospheres; average Reynolds Number, 965,000.

TABLE XXIV

[Airfoil section, Clark Y; model No., 14; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−6.0	311	−0.045	0.0118
−4.5	311	.067	.0112
−3.0	312	.176	.0121
−1.5	312	.287	.0145
0.0	308	.401	.0185
1.5	305	.504	.0235
3.0	302	.616	.0286
4.5	305	.721	.0384
6.0	304	.832	.0461
9.0	304	1.025	.0691
12.0	304	1.213	.0976
15.0	304	1.318	.1295
18.0	303	1.254	.2100
21.0	301	1.070	.2857

Average temperature, 28° C.; average tank pressure, 10.2 atmospheres; average Reynolds Number 1,850,000.

TABLE XXV

[Airfoil section, Clark Y; model No., 14; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m.^{2}; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient	Moment coefficient[1]
Degrees	q, kg/m^2	C_L	C_D	C_M
−6.0	631	−0.060	0.0108	−0.083
−4.5	629	.045	.0107	−.080
−3.0	637	.167	.0119	−.078
−1.5	635	.268	.0139	−.078
0.0	637	.384	.0172	−.070
1.5	629	.501	.0228	−.059
3.0	634	.602	.0288	−.073
6.0	632	.819	.0464	−.079
9.0	631	1.034	.0700	−.054
12.0	630	1.231	.0985	−.036
15.0	630	1.367	.1272	−.077
18.0	623	1.283	.2108	−.056
21.0	616	1.081	.2946	−.048

[1] Moments taken about a point at 25 per cent of the chord.

Average temperature, 36 °C.; average tank pressure, 20.4 atmospheres; average Reynolds Number, 3,610,000.

TABLE XXVI

[Airfoil section, R. A. F. 15; model No., 19; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m.^{2}; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−3.0	28.6	−0.076	0.0129
−1.5	28.7	.054	.0102
0.0	28.7	.187	.0107
1.5	28.4	.298	.0123
3.0	28.6	.404	.0170
4.5	28.6	.512	.0220
6.0	28.4	.626	.0302
9.0	28.6	.838	.0490
12.0	28.6	1.022	.0738
15.0	28.6	1.066	.1391
18.0	28.6	1.018	.2706
21.0	28.4	.895	.3338

Average temperature 17° C.; average tank pressure 1 atmosphere; average Reynolds Number, 185,000

TABLE XXVII

[Airfoil section, R. A. F. 15; model No. 19; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m.^{2}; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−3.0	73.3	−0.042	0.0107
−1.5	73.2	.068	.0093
0.0	73.2	.179	.0102
1.5	72.8	.289	.0128
3.0	72.8	.402	.0164
4.5	72.8	.513	.0217
6.0	72.8	.642	.0285
9.0	72.8	.849	.0468
12.0	72.8	1.031	.0735
15.0	73.4	1.059	.1498
18.0	72.0	1.020	.2672
21.0	72.0	.922	.3398

Average temperature, 18° C.; average tank pressure, 2.51 atmospheres; average Reynolds Number 461,000

TABLE XXVIII

[Airfoil section, R. A. F. 15; model No., 19; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−3.0	153.0	−0.042	0.0100
−1.5	153.0	.061	.0097
0.0	153.0	.179	.0112
1.5	153.0	.292	.0127
3.0	153.0	.404	.0162
4.5	153.0	.512	.0218
6.0	152.8	.628	.0296
9.0	152.8	.841	.0469
12.0	152.8	1.050	.0726
15.0	150.2	1.048	.1376
18.0	151.0	.985	.2400
21.0	150.2	.944	.3288

Average temperature, 21° C.; average tank pressure, 5.1 atmospheres; average Reynolds Number, 950,000.

TABLE XXIX

[Airfoil section, R. A. F. 15; model No., 19; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−4.5	337	−0.152	0.0207
−3.0	338	−.046	.0110
−1.5	340	.055	.0099
0.0	340	.172	.0109
1.5	338	.290	.0134
3.0	342	.401	.0183
4.5	333	.512	.0225
6.0	233	.624	.0300
9.0	334	.845	.0486
12.0	337	1.047	.0720
15.0	332	1.095	.1389
16.0	332	1.061	.1659
18.0	332	.981	.2208
21.0	329	.989	.3238

Average temperature, 21° C.; average tank pressure, 10.75 atmospheres; average Reynolds Number, 2,060,000.

TABLE XXX

[Airfoil section, R. A. F. 15; model No., 19; span 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient	Moment coefficient [1]
Degrees	q, kg/m^2	C_L	C_D	C_M
−4.5	633	−0.162	0.0139	−0.054
−3.0	634	−.052	.0087	−.052
−1.5	634	.052	.0083	−.053
0.0	634	.166	.0088	−.048
1.5	633	.285	.0119	−.045
3.0	632	.398	.0154	−.044
4.5	637	.507	.0205	−.049
6.0	636	.629	.0280	−.045
9.0	636	.850	.0477	−.048
12.0	635	1.068	.0734	−.049
15.0	634	1.209	.0997	−.046
18.0	617	1.004	.2181	−.138
21.0	613	.924	.2872	−.137
16±	615	1.127	.1527	−.077

[1] Moments taken about a point at 25 per cent of the chord.

Average temperature, 36° C.; average tank pressure, 20 atmospheres; average Reynolds Number 3,580,000.

TABLE XXXI

[Airfoil section, Göttingen 387; model No., 20; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters; area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−9.0	26.0	−0.115	0.0770
−6.0	25.4	.114	.0276
−4.5	26.1	.194	.0252
−3.0	26.4	.293	.0272
−1.5	26.4	.402	.0300
0.0	26.1	.542	.0358
1.5	26.1	.650	.0426
3.0	26.1	.761	.0506
4.5	26.1	.860	.0618
6.0	26.1	.971	.0728
9.0	26.1	1.156	.1012
12.0	26.4	1.298	.1352
15.0	26.4	1.396	.1720
18.0	26.4	1.420	.2190
21.0	26.4	1.392	.2730

Average temperature, 22° C.; average tank pressure, 1 atmosphere; average Reynolds Number, 173,000.

TABLE XXXII

[Airfoil section, Göttingen 387; model No., 20; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m^2; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m^2	C_L	C_D
−9.0	68.6	−0.113	0.0657
−6.0	68.0	.090	.0188
−4.5	68.0	.191	.0199
−3.0	68.0	.302	.0211
−1.5	68.0	.412	.0259
0.0	68.0	.530	.0315
1.5	68.0	.642	.0391
3.0	68.0	.748	.0473
6.0	68.0	.961	.0697
9.0	68.1	1.152	.0963
12.0	68.5	1.302	.1269
15.0	67.0	1.383	.1738
18.0	68.2	1.380	.2248
21.0	67.0	1.327	.2860

Average temperature, 23° C.; average tank pressure, 2.52 atmospheres; average Reynolds Number, 440,000.

TABLE XXXIII

[Airfoil section, Göttingen 387; model No., 20; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m²; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m²	C_L	C_D
−9.0	152.0	−0.137	0.0172
−6.0	151.7	.087	.0141
−4.5	151.7	.192	.0141
−3.0	151.5	.314	.0174
−1.5	151.5	.415	.0217
0.0	151.3	.533	.0284
1.5	151.3	.650	.0366
3.0	151.3	.754	.0443
6.0	151.1	.972	.0668
9.0	152.0	1.160	.0924
12.0	152.0	1.320	.1243
15.0	152.0	1.370	.1729
18.0	151.0	1.375	.2309
21.0	150.2	1.296	.2885

Average temperature, 30° C.; average tank pressure, 5.37 atmospheres; average Reynolds Number, 940,000.

TABLE XXXIV

[Airfoil section, Göttingen 387; model No. 20, span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m²; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient
Degrees	q, kg/m²	C_L	C_D
−9.0	306	−0.148	0.0161
−6.0	305	.083	.0130
−4.5	305	.195	.0142
−3.0	306	.306	.0170
−1.5	306	.407	.0219
0.0	306	.524	.0289
1.5	305	.635	.0359
3.0	304	.746	.0455
6.0	305	.953	.0640
9.0	304	1.143	.0916
12.0	304	1.281	.1263
15.0	301	1.309	.1771
18.0	304	1.310	.2336
21.0	302	1.283	.2858

Average temperature, 28° C.; average tank pressure, 10.2 atmospheres; average Reynolds Number, 1,820,000.

TABLE XXXV

[Airfoil section, Göttingen 387; model No. 20; span, 30 inches (76.2 centimeters); chord, 5 inches (12.7 centimeters); area, 0.0968 m²; aspect ratio, 6]

Angle of attack	Dynamic pressure	Lift coefficient	Drag coefficient	Moment coefficient[1]
Degrees	q, kg/m²	C_L	C_D	C_M
−9.0	623	−0.156	0.0154	−0.097
−6.0	623	.061	.0126	−.091
−4.5	622	.168	.0137	−.093
−3.0	622	.280	.0167	−.098
−1.5	617	.390	.0200	−.079
0.0	618	.504	.0266	−.076
1.5	620	.612	.0343	−.080
3.0	622	.725	.0433	−.073
6.0	621	.960	.0651	−.044
9.0	620	1.146	.0917	−.062
12.0	618	1.308	.1227	−.067
15.0	616	1.328	.1731	−.109
18.0	617	1.320	.2347	−.116
21.0	615	1.276	.2894	−.129

[1] Moments taken about a point at 25 per cent of the chord.

Average temperature, 39° C.; average tank pressure, 19.8 atmospheres; average Reynolds Number, 3,470,000.

TABLE XXXVI

Per cent of chord	Section R. A. F. 15		Section U. S. A. 5		Section U. S. A. 27		Section Göttingen 387	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	0. 20	0. 20	0. 73	0. 33	1. 77	1. 77	3. 61	3. 61
1. 25	1. 90	−0. 45	2. 10	0. 17	3. 80	0. 50	6. 74	1. 35
2. 5	2. 75	−0. 71	3. 04	0. 03	5. 07	0. 36	7. 96	0. 80
5	3. 93	−0. 94	4. 42	0. 03	6. 94	0. 16	9. 85	0. 36
7. 5	4. 55	−1. 00	5. 41	0. 25	8. 22	0. 10	11. 32	0. 18
10	5. 06	−1. 00	6. 22	0. 60	9. 19	0. 02	12. 37	0. 08
15	5. 58	−0. 80	7. 20	1. 15	10. 50	0. 10	13. 83	0. 00
20	5. 77	−0. 50	7. 94	1. 59	11. 37	0. 36	14. 77	0. 06
30	5. 85	−0. 04	8. 38	2. 00	11. 97	0. 93	15. 38	0. 20
40	5. 68	−0. 03	8. 17	2. 16	11. 68	1. 14	14. 91	0. 35
50	5. 34	−0. 22	7. 66	1. 94	10. 86	0. 75	13. 41	0. 47
60	4. 78	−0. 46	6. 76	1. 62	9. 54	0. 28	11. 56	0. 56
70	4. 10	−0. 69	5. 62	1. 16	8. 08	0. 06	9. 18	0. 50
80	3. 30	−0. 59	4. 20	0. 77	6. 10	0. 01	6. 57	0. 45
90	2. 26	−0. 32	2. 48	0. 40	3. 69	0. 12	3. 59	0. 25
95	1. 63	−0. 18	1. 50	0. 20	2. 26	0. 33	1. 99	0. 16
100	0. 30	+0. 30	0. 50	0. 00	0. 67	0. 65	0. 37	0. 00

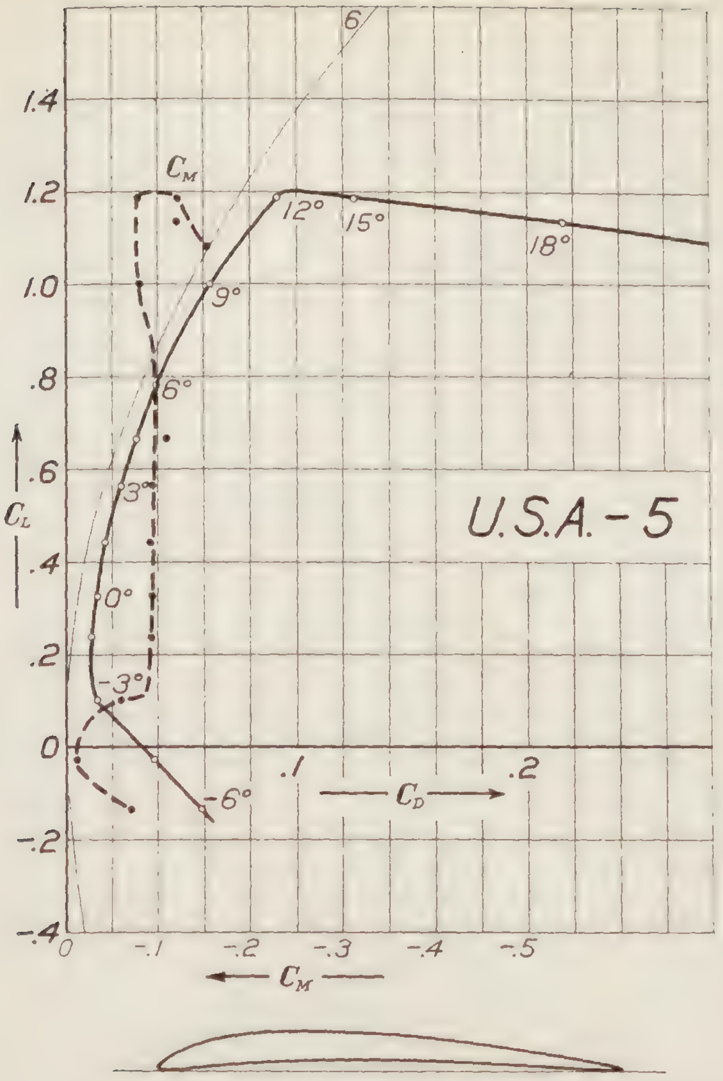
Ordinates of upper and lower boundary of sections at different stations of the chord.

Per cent of chord	Section U. S. A. 35 B		Section U. S. A. 35 A		Section Clark Y	
	Upper	Lower	Upper	Lower	Upper	Lower
0	2. 76	2. 76	4. 33	4. 33	3. 58	3. 62
1. 25	5. 15	1. 03	8. 09	1. 62	5. 38	1. 86
2. 5	6. 11	0. 63	9. 54	1. 00	6. 43	1. 42
5	7. 52	0. 28	11. 81	0. 46	7. 83	0. 91
7. 5	8. 65	0. 14	13. 58	0. 22	8. 79	0. 59
10	9. 45	0. 07	14. 85	0. 10	9. 56	0. 39
15	10. 56	0. 00	16. 60	0. 00	10. 63	0. 12
20	11. 28	0. 05	17. 73	0. 08	11. 32	0. 01
30	11. 76	0. 15	18. 46	0. 24	11. 68	0. 00
40	11. 42	0. 28	17. 89	0. 40	11. 37	0. 00
50	10. 33	0. 39	16. 21	0. 58	10. 49	0. 00
60	8. 81	0. 45	13. 83	0. 66	9. 13	0. 00
70	7. 08	0. 42	11. 11	0. 60	7. 34	0. 00
80	5. 02	0. 35	7. 88	0. 50	5. 21	0. 00
90	2. 72	0. 20	4. 31	0. 32	2. 79	0. 00
95	1. 50	0. 12	2. 39	0. 19	1. 50	0. 00
100	0. 25	0. 00	0. 43	0. 00	0. 12	0. 00

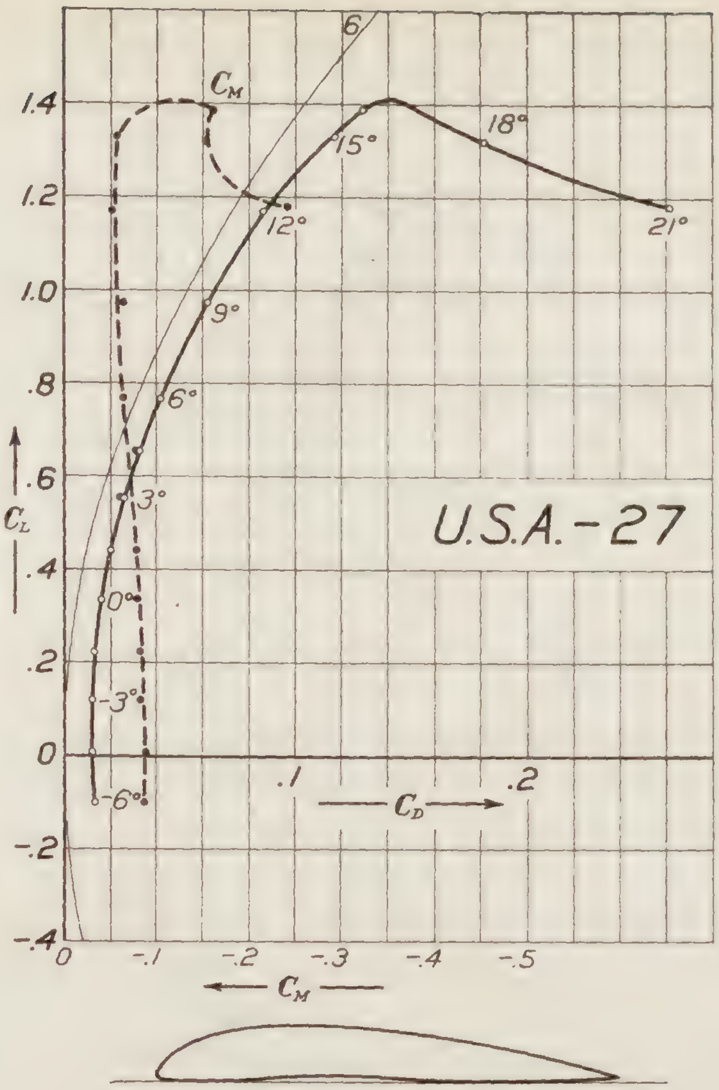
TABLE XXXVII

SUMMARY OF TEST DATA FOR COMPARISON

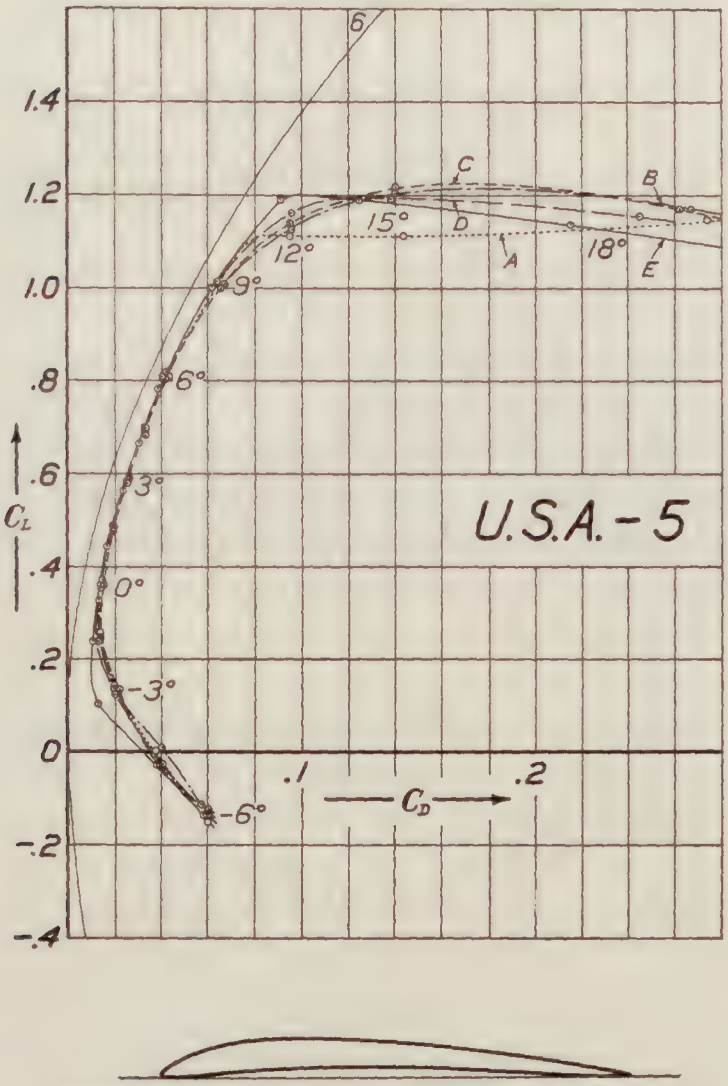
Airfoil section	Tank pressure atmospheres	Reynolds Number	Maximum lift C_L max.	Minimum drag C_D min.	Ratio $\frac{C_L \text{ max.}}{C_D \text{ min.}}$	Maximum ratio L/D	Maximum ratio (C_L^3/C_D^2)
U. S. A. 5	1. 00	179, 000	1. 150	0. 0140	82. 1	25. 0	7, 760
	2. 62	482, 000	1. 205	. 0138	87. 0	25. 0	9, 187
	4. 86	863, 000	1. 220	. 0139	87. 8	23. 6	9, 398
	10. 48	1, 840, 000	1. 195	. 0123	97. 2	24. 3	11, 280
	20. 07	3, 630, 000	1. 200	. 0113	106. 2	24. 7	13, 533
U. S. A. 27	1. 00	175, 000	1. 310	. 0160	81. 8	20. 6	8, 782
	2. 58	456, 000	1. 215	. 0149	81. 3	21. 8	8, 078
	5. 10	900, 000	1. 210	. 0131	92. 3	23. 3	10, 323
	10. 14	1, 890, 000	1. 295	. 0117	110. 6	21. 6	15, 865
	19. 92	3, 570, 000	1. 387	. 0115	120. 5	22. 3	20, 176
U. S. A. 35 A	1. 00	180, 000	1. 580	. 0226	70. 0	18. 2	7, 722
	2. 48	450, 000	1. 500	. 0189	79. 4	18. 6	9, 448
	5. 37	960, 000	1. 440	. 0142	101. 3	19. 9	14, 808
	10. 25	1, 860, 000	1. 240	. 0148	83. 8	19. 9	8, 704
	20. 30	3, 520, 000	1. 210	. 0138	87. 6	19. 6	9, 302
U. S. A. 35 B	1. 00	163, 000	1. 250	. 0207	60. 3	16. 7	4, 558
	2. 45	415, 000	1. 254	. 0141	89. 0	19. 4	9, 919
	5. 24	859, 000	1. 301	. 0110	118. 3	20. 1	18, 199
	10. 20	1, 695, 000	1. 380	. 0100	138. 0	20. 8	26, 281
	19. 82	3, 470, 000	1. 380	. 0092	150. 2	21. 8	31, 050
Clark Y	1. 00	181, 000	1. 215	. 0127	95. 6	25. 1	11, 120
	2. 52	480, 000	1. 190	. 0105	113. 3	24. 1	15, 285
	5. 44	965, 000	1. 197	. 0097	123. 4	24. 0	18, 228
	10. 20	1, 850, 000	1. 330	. 0112	118. 8	22. 1	18, 755
	20. 40	3, 610, 000	1. 373	. 0106	129. 5	22. 4	23, 036
R. A. F. 15	1. 00	185, 000	1. 067	. 0101	105. 7	24. 5	11, 908
	2. 51	461, 000	1. 061	. 0093	114. 0	24. 5	13, 809
	5. 10	950, 000	1. 063	. 0094	113. 0	25. 0	13, 594
	10. 75	2, 060, 000	1. 095	. 0099	110. 6	23. 6	13, 396
	20. 00	3, 580, 000	1. 216	. 0083	146. 6	25. 8	26, 100
Göttingen 387	1. 00	173, 000	1. 420	. 0272	51. 2	15. 3	3, 870
	2. 52	440, 000	1. 395	. 0188	74. 1	16. 8	7, 686
	5. 37	940, 000	1. 380	. 0136	101. 5	19. 2	14, 209
	10. 20	1, 820, 000	1. 310	. 0128	102. 3	18. 7	13, 721
	19. 80	3, 470, 000	1. 330	. 0124	107. 3	19. 6	15, 301



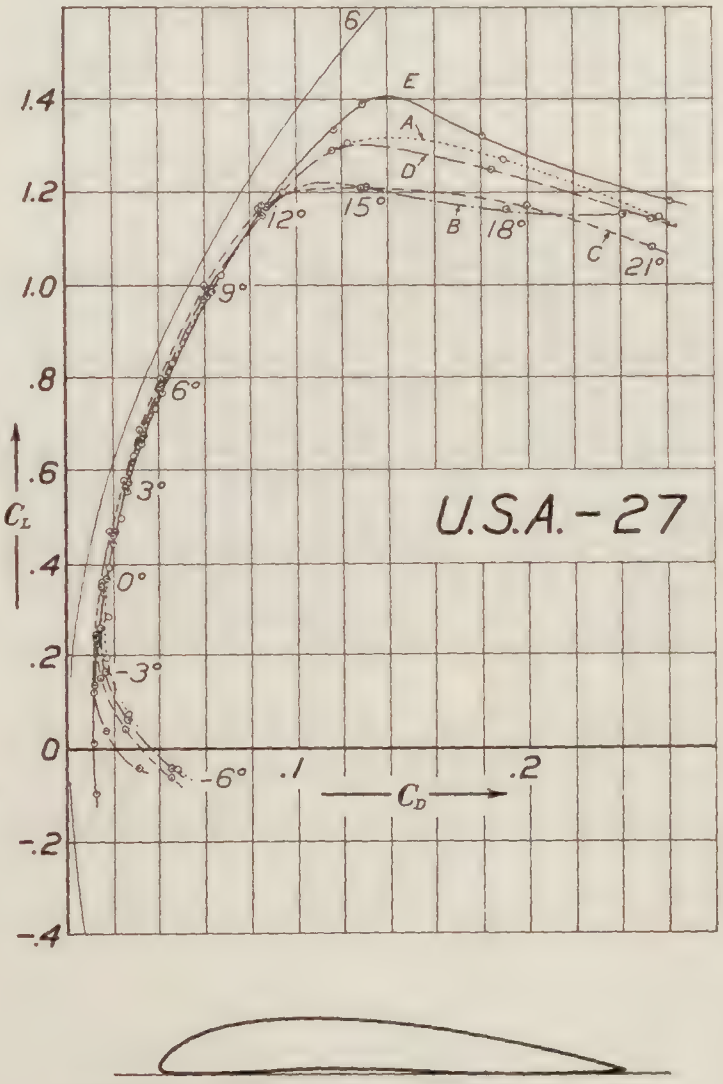
Tank pressure, atmospheres	Dynamic pressure q=kg/m²	Reynolds Number
20.07	640.00	3,630,000



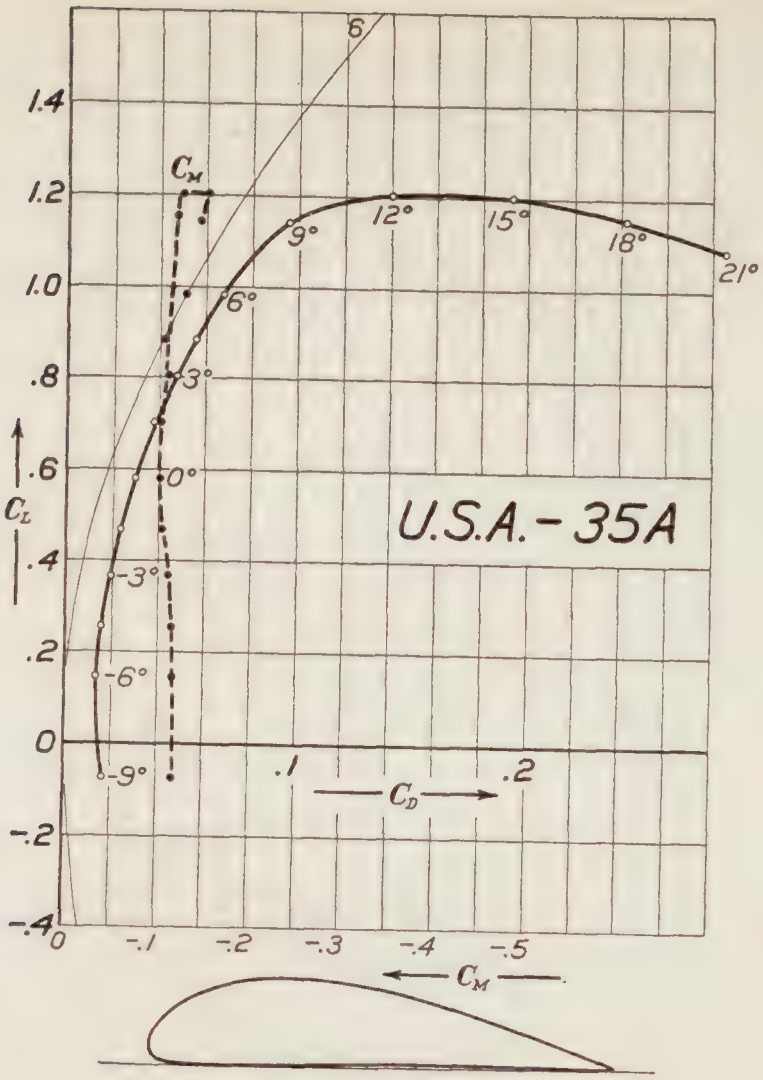
Tank pressure, atmospheres	Dynamic pressure q=kg/m²	Reynolds Number
19.92	636.00	3,570,000



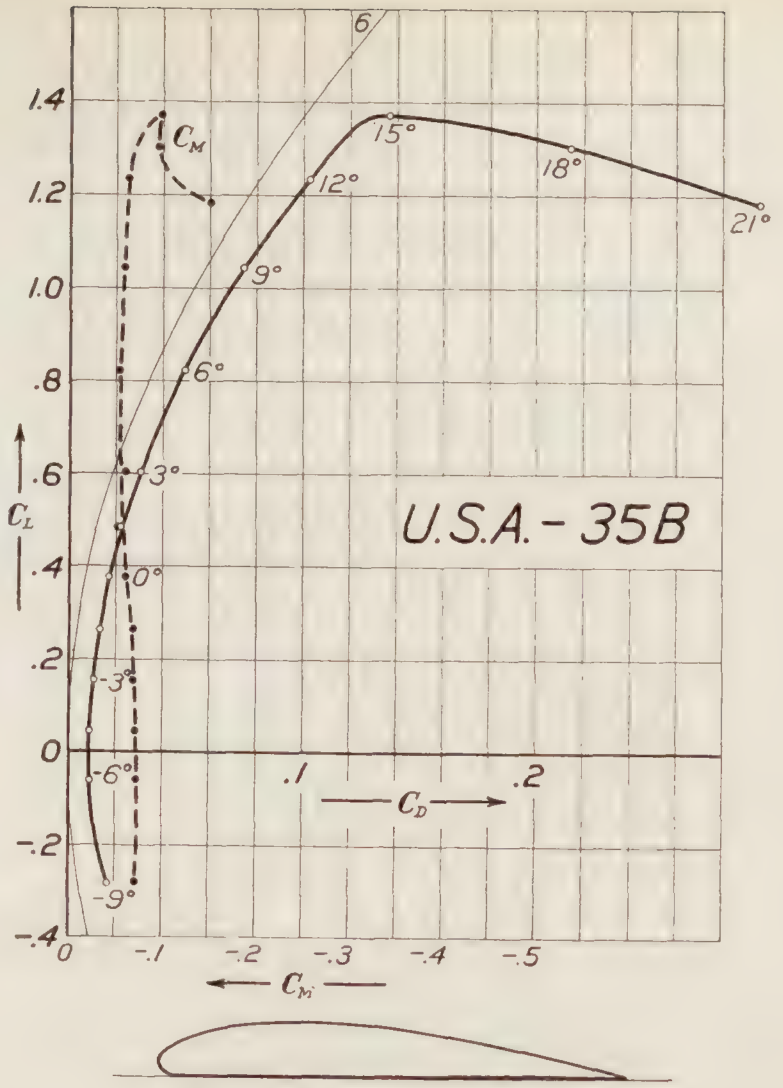
	Tank pressure, atmospheres	Dynamic pressure q=kg/m²	Reynolds Number
Curve A	1.00	28.00	179,000
Curve B	2.62	76.10	482,000
Curve C	4.86	139.20	863,000
Curve D	10.48	310.00	1,840,000
Curve E	20.07	640.00	3,630,000



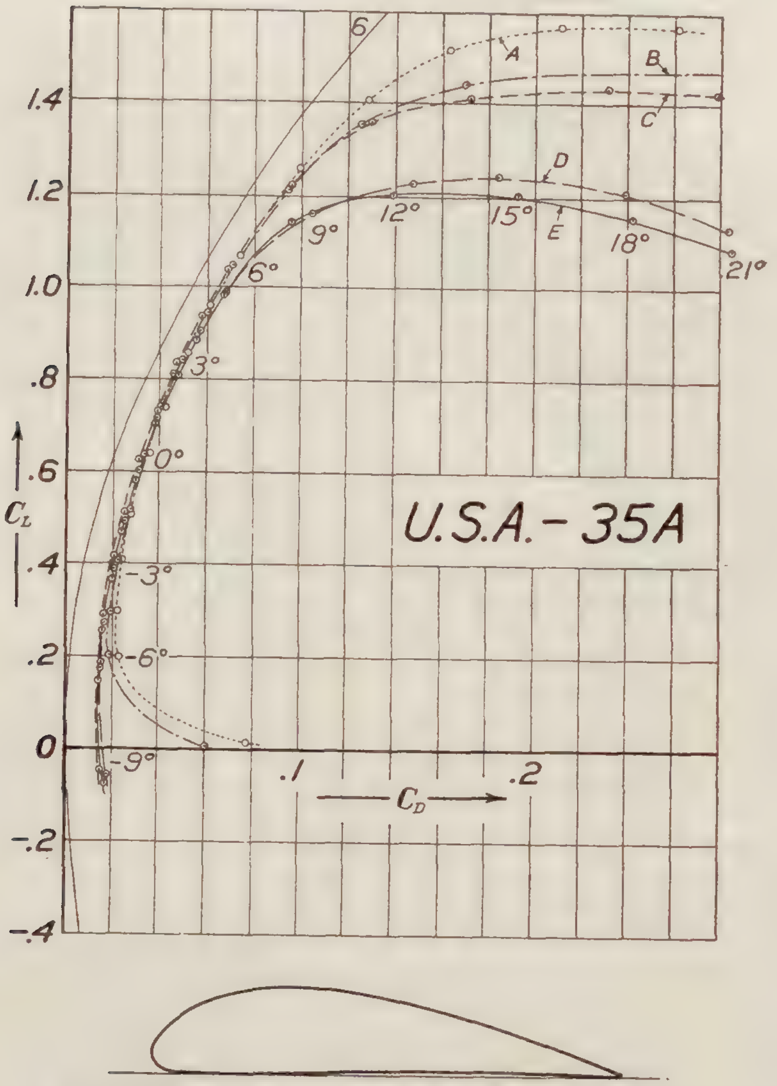
	Tank pressure, atmospheres	Dynamic pressure q=kg/m³	Reynolds Number
Curve A	1.00	27.00	175,000
Curve B	2.58	72.50	456,000
Curve C	5.10	147.00	900,000
Curve D	10.14	318.00	1,890,000
Curve E	19.92	636.00	3,570,000



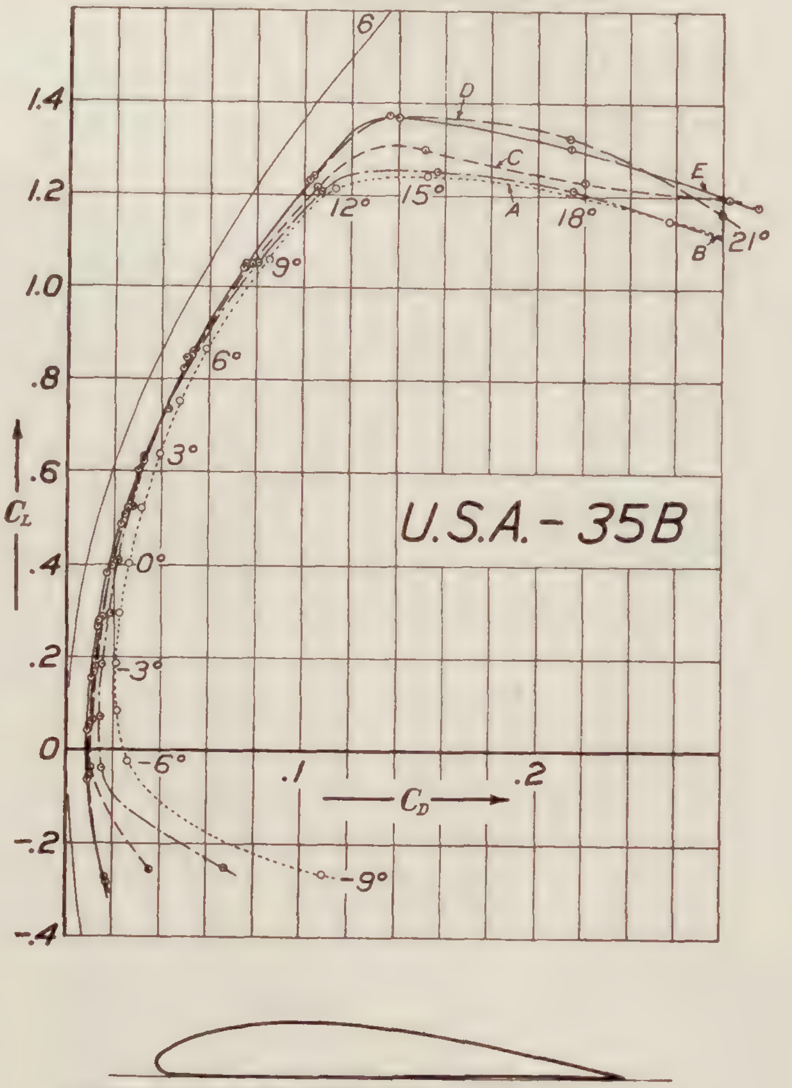
Tank pressure, atmospheres	Dynamic pressure q=kg/m²	Reynolds Number
20.30	624.00	3,520,000



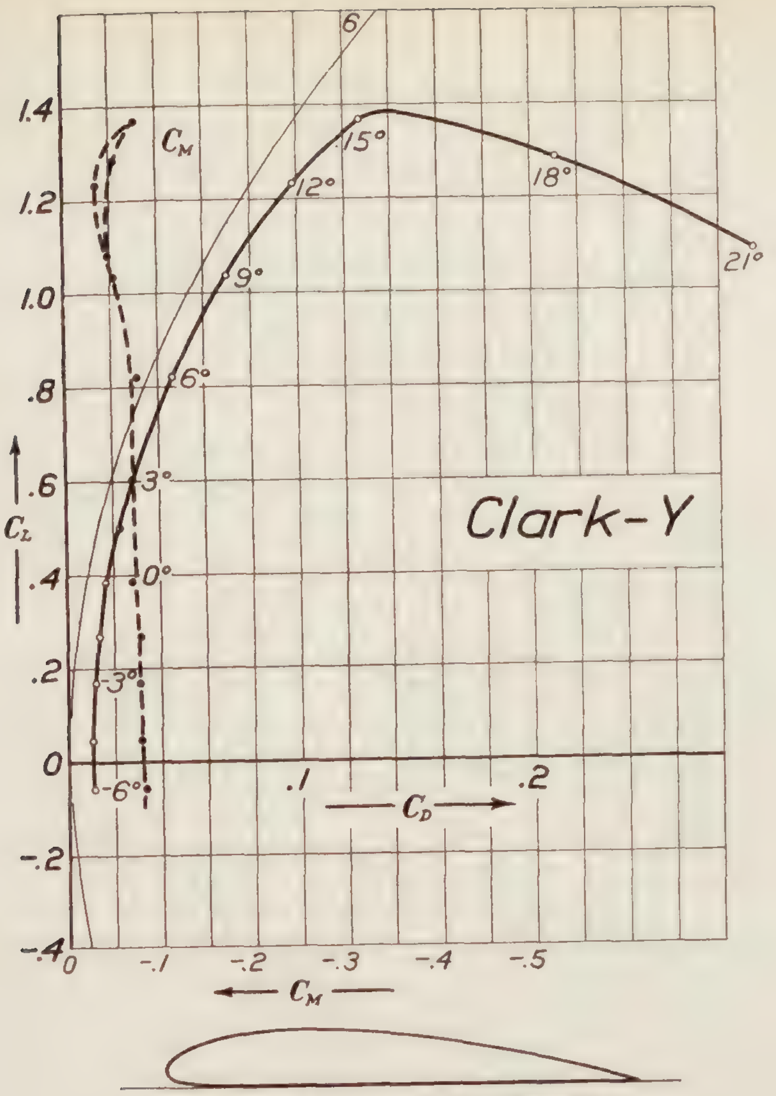
Tank pressure, atmospheres	Dynamic pressure q=kg/m²	Reynolds Number
19.82	622.00	3,470,000



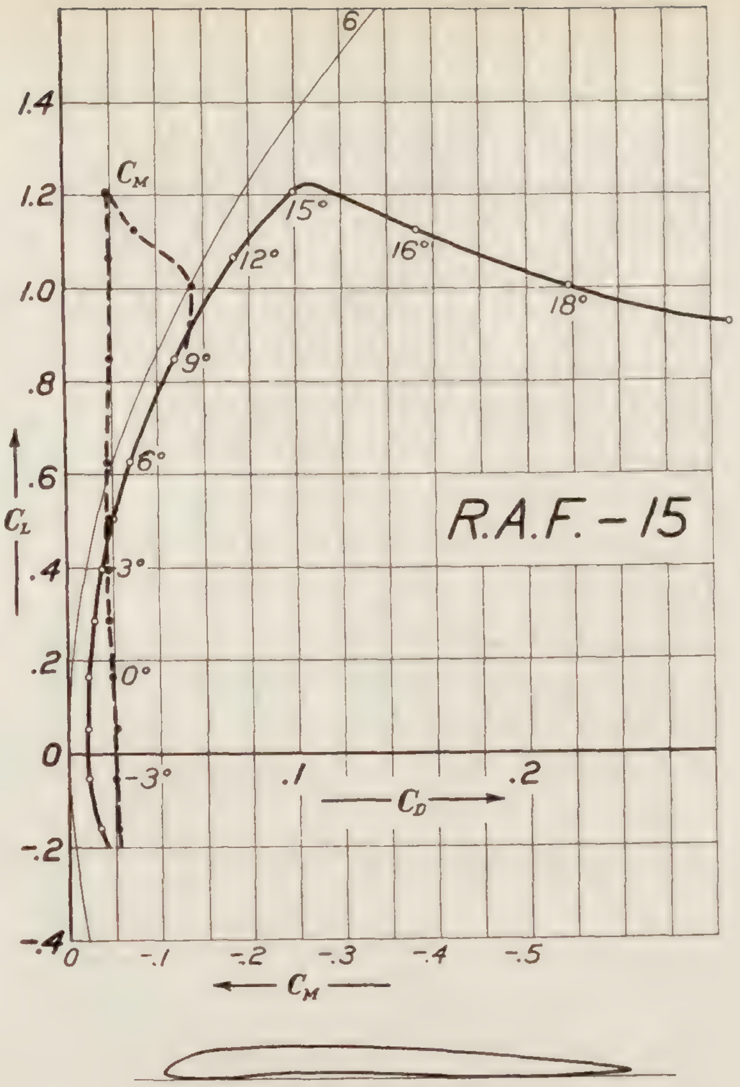
	Tank pressure, atmospheres	Dynamic pressure q=kg/m²	Reynolds Number
Curve A	1.00	28.00	180,000
Curve B	2.48	72.00	450,000
Curve C	5.37	156.00	960,000
Curve D	10.25	310.00	1,860,000
Curve E	20.30	624.00	3,520,000



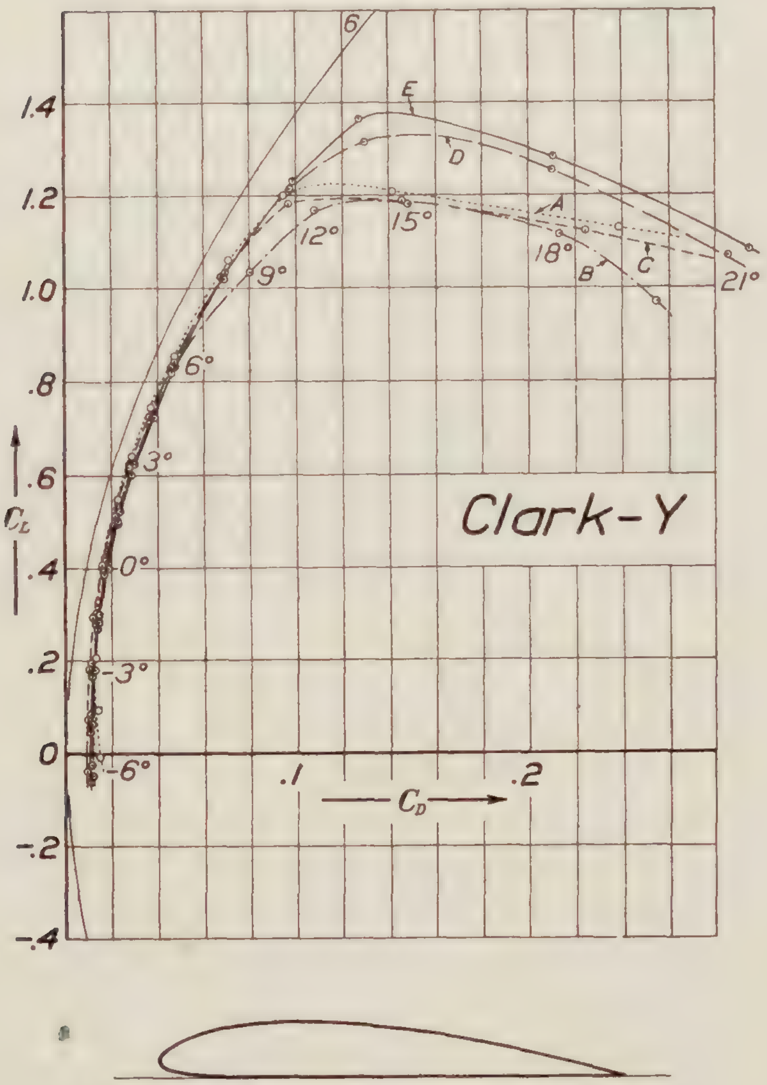
	Tank pressure, atmospheres	Dynamic pressure q=kg/m²	Reynolds Number
Curve A	1.00	25.20	163,000
Curve B	2.45	65.00	415,000
Curve C	5.24	145.00	859,000
Curve D	10.20	289.50	1,695,000
Curve E	19.82	622.00	3,470,000



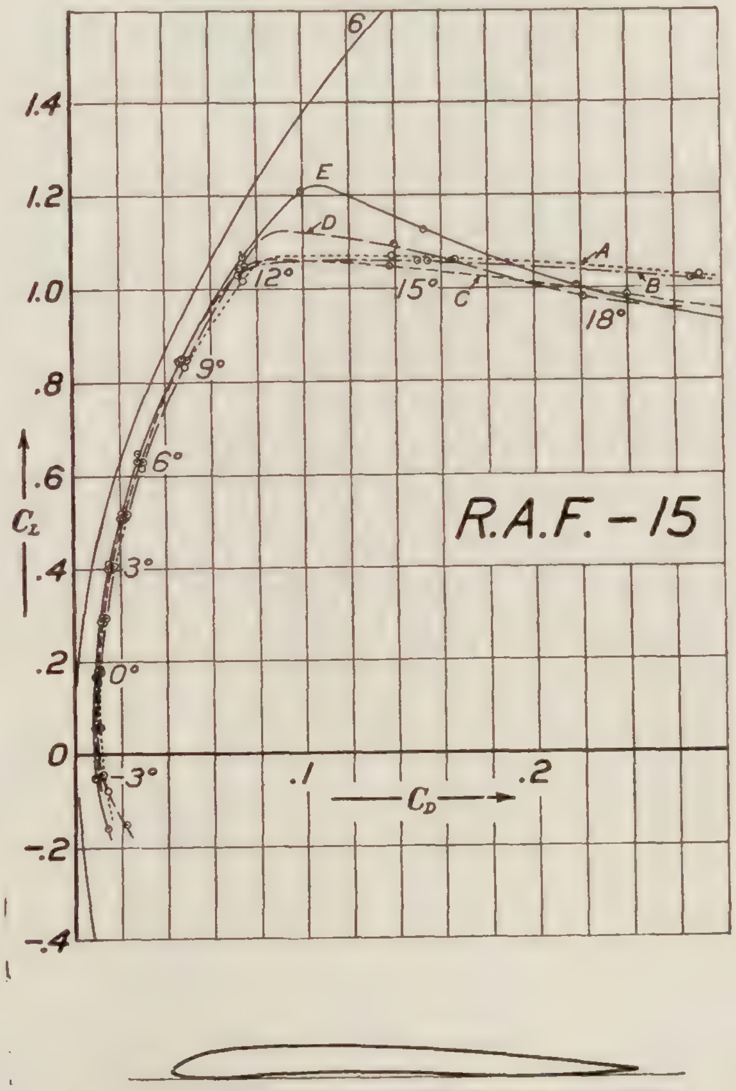
Tank pressure, atmospheres	Dynamic pressure q=kg/m²	Reynolds Number
20.40	632.00	3,610,000



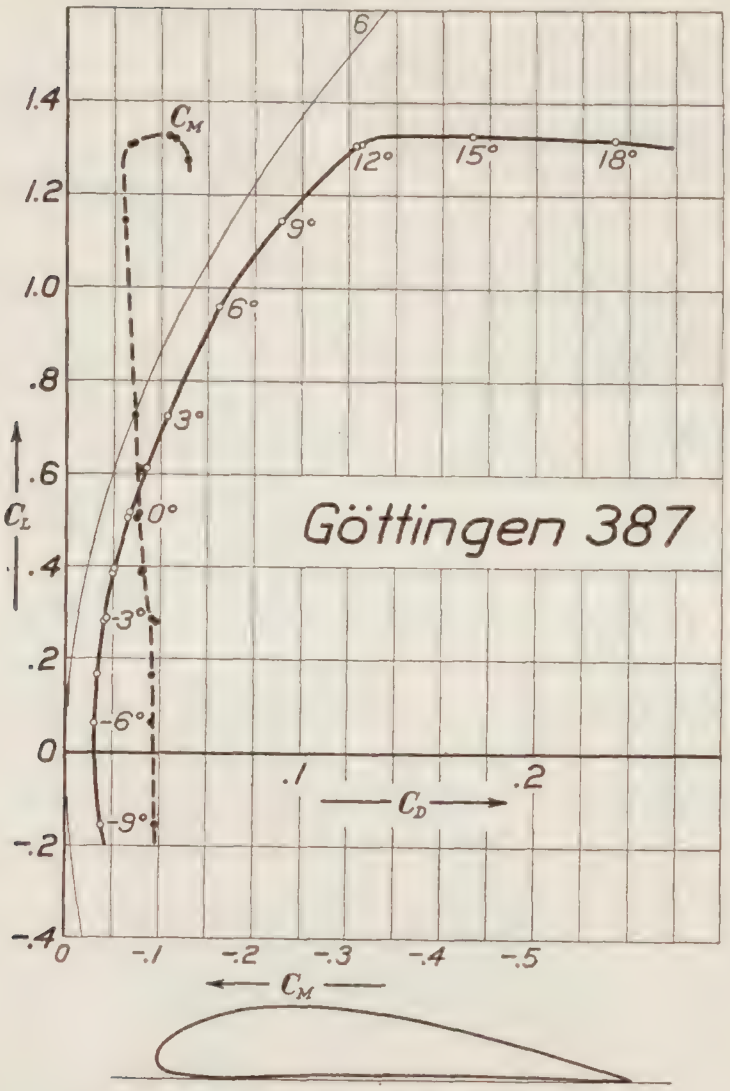
Tank pressure, atmospheres	Dynamic pressure q=kg/m²	Reynolds Number
20.00	630.00	3,580,000



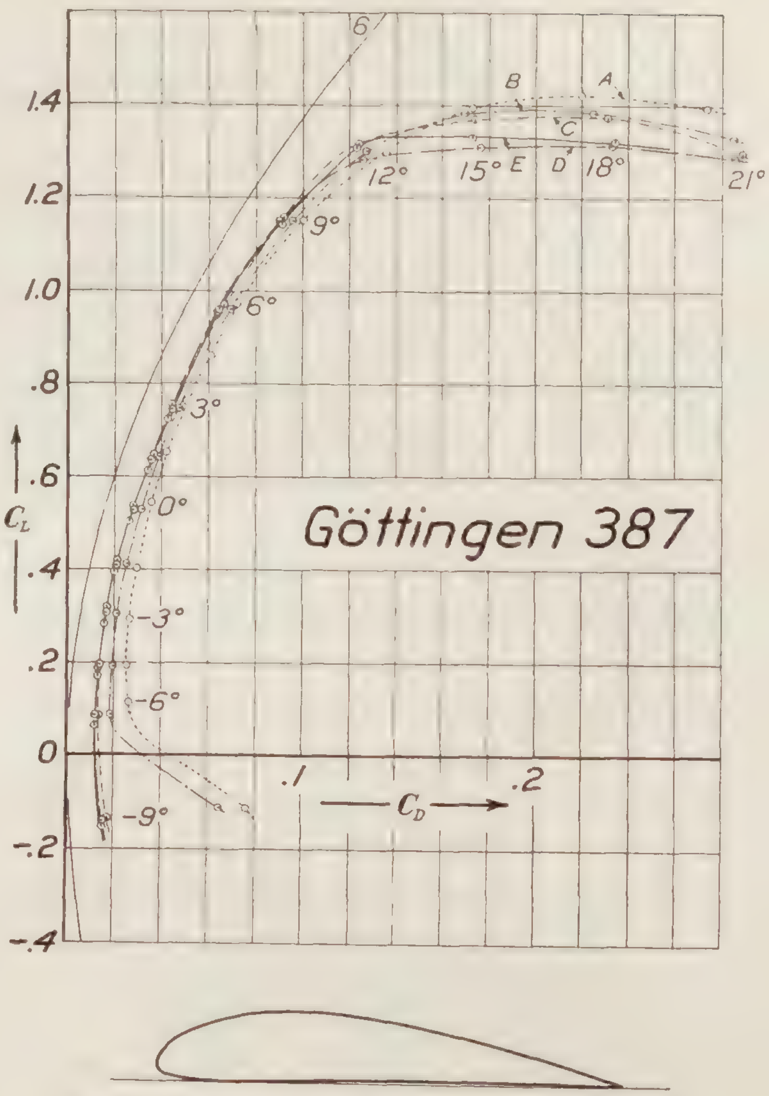
	Tank pressure, atmospheres	Dynamic pressure q=kg/m²	Reynolds Number
Curve A	1.00	28.10	181,000
Curve B	2.52	71.80	460,000
Curve C	5.44	155.00	965,000
Curve D	10.20	353.00	1,850,000
Curve E	20.40	632.00	3,610,000



	Tank pressure, atmospheres	Dynamic pressure q=kg/m²	Reynolds Number
Curve A	1.00	28.60	185,000
Curve B	2.51	72.70	461,000
Curve C	5.10	152.00	950,000
Curve D	10.75	335.00	2,060,000
Curve E	20.00	630.00	3,580,000



Tank pressure, atmospheres	Dynamic pressure q=kg/m²	Reynolds Number
19. 80	620. 00	3, 470, 000



	Tank pressure, atmospheres	Dynamic pressure q=kg/m²	Reynolds Number
Curve A	1. 00	26. 25	173, 000
Curve B	2. 52	67. 80	440, 000
Curve C	5. 37	151. 00	940, 000
Curve D	10. 20	305. 00	1, 820, 000
Curve E	19. 80	620. 00	3, 470, 000

REPORT No. 234

THREE METHODS OF CALCULATING RANGE AND ENDURANCE OF AIRPLANES

By WALTER S. DIEHL
Bureau of Aeronautics
Navy Department

REPORT No. 234

THREE METHODS OF CALCULATING RANGE AND ENDURANCE OF AIRPLANES

By Walter S. Diehl

SUMMARY

This report, which was prepared for the National Advisory Committee for Aeronautics, develops new equations which give the range and endurance of airplanes with an accuracy equal to that obtained from a step-by-step integration of the flight. A method of obtaining equally satisfactory results from Breguet's equations is also given in detail. A third method of calculating range and endurance, derived by the writer for use in routine estimating in the Bureau of Aeronautics, is also given in full.

The report contains tables and curves arranged for convenient use and illustrates the three methods by comparative estimates.

INTRODUCTION

It has been customary to calculate the range and endurance of airplanes either from a step-by-step integration or by means of the common equations for range and endurance, usually known as Breguet's equations. Although the work involved in a calculation with the equations is only a small fraction of that required in a step-by-step integration, the latter method has been almost universally used for accurate work, owing to the inability of many engineers to secure accurate or consistent values with the equations.

This study was started for the purpose of developing new equations which would give definite results equal in accuracy to a step-by-step integration. After the new equations were developed it was found that while they fulfilled the requirements of simplicity and accuracy, the same results could be obtained from Breguet's equations by the use of new data on specific fuel consumption. This paper therefore not only supplies the aeronautical engineer with new equations for calculating range and endurance with the accuracy of a step-by-step integration, but it also gives a method whereby the same results can be obtained from Breguet's equations. This is a matter of considerable importance, since it is no longer necessary to carry through a step-by-step integration in order to secure accurate cruising ranges and endurances.

An additional method of calculating cruising range and endurance is given in full in this paper. This method, which was developed by the writer for routine estimating in the Bureau of Aeronautics, may be called the "factor method," since the range and endurance at cruising speed are found by multiplying the range and endurance at high speed by easily determined factors. While the factor method is slightly less accurate than the equations, it gives very satisfactory results for routine estimations.

In this report cruising speed will be the air speed at which the fuel consumption in pounds per mile is a minimum. This designation should be noted carefully, since any normal speed in throttled flight is frequently called cruising speed. If the term "cruising speed" is to apply to any speed of throttled flight, the particular cruising speed used in this report is the "most economical cruising speed" giving the maximum range (but not the maximum endurance).

The basis of the present study is found in two average curves of specific fuel consumption which were originally prepared by Mr. R. M. Parsons and Commander E. E. Wilson, United States Navy, for the Bureau of Aeronautics. The specific fuel consumption of an individual engine may vary slightly from the average, but a great number of comparisons indicate that these curves fairly represent any standard engine or carburetor now in service.

A word of caution is perhaps necessary in regard to the use of the data for special mixture control. This requires that the mixture control be constantly adjusted during the flight so as to give the minimum fuel consumption at all times. Owing to the special training and skill required for this purpose, the cases where the special mixture control data can be used are very few.

BREGUET'S EQUATIONS FOR RANGE AND ENDURANCE

Breguet's equations for range and endurance of airplanes are—

$$\text{Range miles} = 863.5 \left(\frac{L}{D}\right)\left(\frac{\eta}{c}\right) \log_{10}\left(\frac{W_0}{W_1}\right) \tag{1}$$

$$\text{Endurance hours} = 750 \frac{V_c}{\sqrt{W}}\left(\frac{L}{D}\right)\left(\frac{\eta}{c}\right)\left[\frac{1}{\sqrt{W_1}} - \frac{1}{\sqrt{W_0}}\right] \tag{2}$$

where (L/D) is the ratio of lift to the drag of the entire airplane at the cruising angle of attack, η the cruising propeller efficiency, c the cruising specific fuel consumption in pounds per B.HP. per hour, W_0 the initial gross weight in pounds, and W_1 the final gross weight in pounds. $(W_0 - W_1)$ is therefore the fuel consumed in the flight. For cruising at a constant angle of attack the ratio of $(V_c/\sqrt{W})$ is constant.

In view of the simple and straightforward derivation of these equations (see reference 1) it has been rather disappointing to many engineers to find that the range and endurance calculated by their use is often very optimistic. This condition is entirely due to the fact that the specific fuel consumption varies between wide limits, which are difficult to determine from the usual engine data. However, the equations are fundamentally correct and can be made to give excellent results, even in the hand of an inexperienced calculator, when the variation of specific fuel consumption with weight and speed range ratio is known.

Data for determining the average specific fuel consumption and explicit instructions for using equations (1) and (2) will be given later.

THE VARIATION OF SPECIFIC FUEL CONSUMPTION WITH AIRPLANE WEIGHT

Consider an airplane in horizontal flight at cruising speed and assume that—

1. The flight is to be made at a constant angle of attack, i. e., C_L and L/D constant.
2. The brake horsepower B.HP. varies as the cube of the R.P.M. for throttled conditions, i. e.

$$\frac{\text{B.HP.}}{\text{B.HP.}_0} = \left(\frac{N}{N_0}\right)^3$$

It then follows that the air speed V varies as the square root of the weight W

$$V = K_1\sqrt{W} \tag{3}$$

and the thrust horsepower required is

$$\text{T.HP.} = \frac{WV}{K_2\left(\frac{L}{D}\right)} = \frac{K_1 W^{1.5}}{K_2\left(\frac{L}{D}\right)} \tag{4}$$

Since T.HP. $= \eta$ B.HP. $= \eta\ K\ N^3$, it may be shown that (V/N), and consequently the propeller efficiency η, is constant. Therefore,

$$\frac{\text{B.HP.}}{\text{B.HP.}_0} = \left(\frac{V}{V_0}\right)^3 = \left(\frac{W}{W_0}\right)^{1.5} \tag{5}$$

Values of the specific fuel consumption ratio c/c_0 are given for throttled conditions in Table I or Figure 1. Plotting these data logarithmically as in Figure 2, it is found that for general service operation at throttled powers less than 70 per cent of the full power, B.HP.$_0$

$$c=c_1\left(\frac{\text{B.HP.}_0}{\text{B.HP.}}\right)^{.30} \tag{6}$$

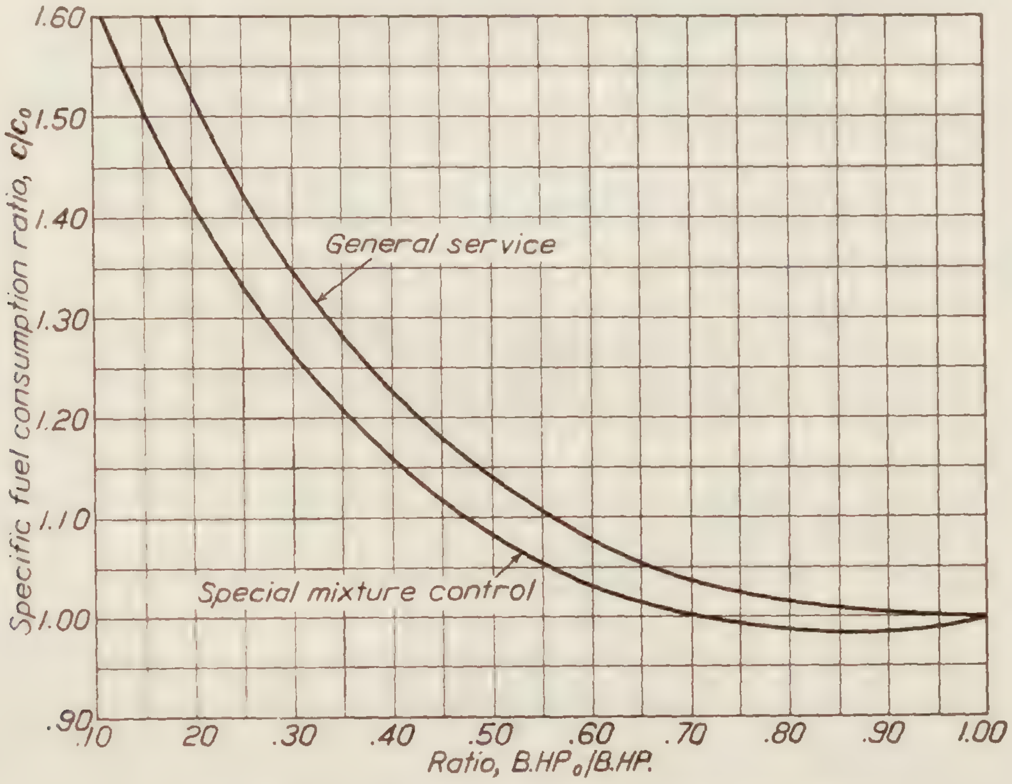


FIG. 1.—Relation between specific fuel consumption and brake horsepower

where c is the instantaneous specific fuel consumption and c_1 the initial specific fuel consumption. In a similar manner it is found that with special mixture control for the leanest mixture practicable

$$c=c_1\left(\frac{\text{B.HP.}_0}{\text{B.HP.}}\right)^{.28} \tag{7}$$

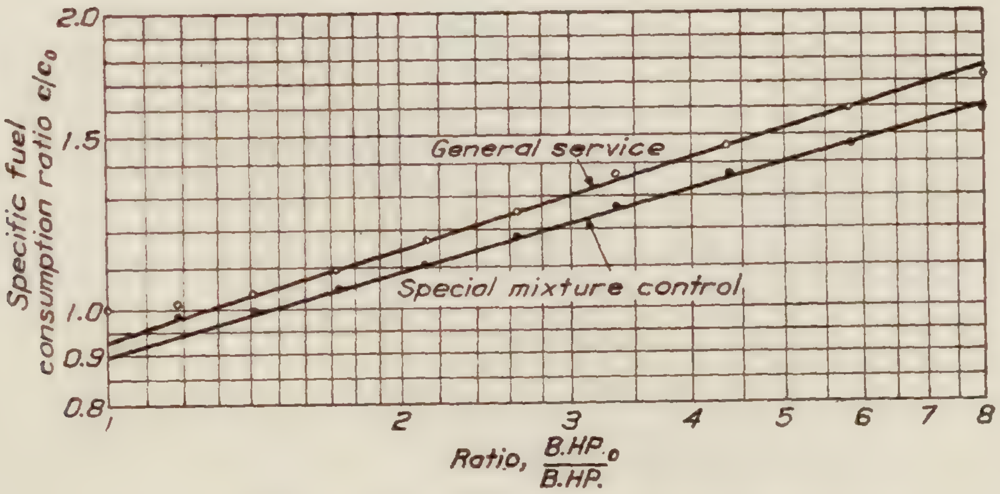


FIG 2.—Relation between specific fuel consumption and brake horsepower

General service, $c/c_0=.93\left(\frac{\text{B. HP}_0}{\text{B. HP}}\right)^{.30}$

Special mixture control, $c/c_0=.90\left(\frac{\text{B. HP}_0}{\text{B. HP}}\right)^{.28}$

Substituting equations (6) and (7) into (5), one obtains for general service operating conditions

$$c=c_1\left(\frac{W_0}{W}\right)^{.45} \tag{8}$$

and for special mixture control

$$c=c_1\left(\frac{W_0}{W}\right)^{.42} \tag{9}$$

The initial specific fuel consumption at cruising speed c_1 is really determined from the speed range ratio with full load. The calculations may be found in Table IX and a plot of c_1 against V_m/V_s is given in Figure 9.

c_1 must not be confused with the specific fuel consumption at full throttle c_0. The latter is a function of the compression ratio and has the average values given in Table II. These values may be represented by the empirical equation

$$c_0 = 0.75 - 0.04\ C.R. \tag{10}$$

where $C.R.$ is the compression ratio and c_0 the specific fuel consumption at full throttle, in lb./B.HP./hr.

DERIVATION OF NEW EQUATIONS FOR RANGE

The rate of change of weight is

$$\frac{dw}{dt} = -\text{B.HP. } c = \frac{-\text{T.HP.}}{\eta}\, c \tag{11}$$

from which

$$dt = \frac{-\eta\, dw}{\text{T.HP. } c}$$

Substituting the value of T.HP. from (4) gives

$$dt = \frac{-K_2 \eta \left(\frac{L}{D}\right) dw}{K_1\, W^{1.5}\, c}$$

Consider the general case of equations (8) and (9), where

$$c = c_1 \left(\frac{W_0}{W}\right)^n$$

Substituting this gives

$$dt = \frac{-K_2 \eta \left(\frac{L}{D}\right) dw}{c_1 K_1 W_0^n\, W^{(1.5-n)}} \tag{12}$$

The range is

$$R = \int V dt = \int K_1 \sqrt{W}\, dt$$

$$R = \int_{W_0}^{W_1} \frac{K_2 \eta \left(\frac{L}{D}\right) dw}{c_1 W_0^n\, W^{1-n}}$$

$$= \frac{K_2 \eta \left(\frac{L}{D}\right)}{c_1 W_0^n n} \left[W_0^n - W_1^n \right] \tag{13}$$

For the usual units, W in lb., V in M.P.H., c_0 in lb./B.HP./hr., and R in miles, K_2 has the value 375. The general equation for range is therefore

$$R = \frac{375 \eta \left(\frac{L}{D}\right)}{c_1 n} \left[1 - \left(\frac{W_1}{W_0}\right)^n \right] \tag{13a}$$

Upon substitution of the proper values for n, this equation is applicable to the two cases under consideration:

CASE I. GENERAL SERVICE—NO MIXTURE CONTROL

$$n = 0.45$$

$$R = 833.3 \left(\frac{\eta}{c_1}\right) \left(\frac{L}{D}\right) \left[1 - \left(\frac{W_1}{W_0}\right)^{.45} \right] \tag{14}$$

CASE II. SPECIAL MIXTURE CONTROL FOR LEANEST MIXTURE PRACTICABLE

$$n=0.42$$

$$R=892.9\left(\frac{\eta}{c_1}\right)\left(\frac{L}{D}\right)\left[1-\left(\frac{W_1}{W_0}\right)^{0.42}\right] \tag{15}$$

DERIVATION OF NEW EQUATIONS FOR ENDURANCE

The endurance may be obtained by integrating equation (12):

$$dt=\frac{K_2\ \eta\left(\frac{L}{D}\right)dw}{c_1 K_1\ (W_0)^n\ W^{(1.5-n)}} \tag{12}$$

$$t=\frac{K_2\ \eta\left(\frac{L}{D}\right)}{c_1 K_1\ (W_0)}\int_{W_0}^{W_1}\frac{dw}{W^{1.5-n}}$$

$$=\frac{K_2\ \eta\left(\frac{L}{D}\right)}{c_1 K_1\ (W_0)^n\ (n-0.5)}\left[W_0^{(n-0.5)}-W_1^{(n-0.5)}\right]$$

$$=\frac{K_2\ \eta\left(\frac{L}{D}\right)}{c_1 K_1\ W_0^{0.5}\ (n-0.5)}\left[1-\left(\frac{W_1}{W_0}\right)^{n-0.5}\right]$$

Since $K_1\ W_0^{0.5}=V_0$ and $K_2=375$

$$t=\frac{375\ \eta\left(\frac{L}{D}\right)}{c_1 V_0\ (n-0.5)}\left[1-\left(\frac{W_1}{W_0}\right)^{n-0.5}\right] \tag{16}$$

Upon substitution of the proper values for n this general equation is applicable to the two cases under consideration.

CASE I.—GENERAL SERVICE—NO MIXTURE CONTROL

$$n=0.45$$

$$T=7500\left(\frac{\eta}{c_1}\right)\left(\frac{L}{D}\right)\frac{1}{V_{c_0}}\left[\left(\frac{W_0}{W_1}\right)^{.05}-1\right] \tag{17}$$

CASE II. SPECIAL MIXTURE CONTROL FOR LEANEST MIXTURE PRACTICABLE

$$n=0.42$$

$$T=4687.5\left(\frac{\eta}{c_1}\right)\left(\frac{L}{D}\right)\frac{1}{V_{c_0}}\left[\left(\frac{W_0}{W_1}\right)^{.08}-1\right] \tag{18}$$

In equations (17) and (18), V_{c_0} is the initial cruising speed in M.P.H. Unless great exactness is required V_{c_0} may be taken as 1.4 times the stalling speed as determined by the initial weight, the maximum lift coefficient, and the wing area. This approximation gives a speed which rarely differs more than two M.P.H. (or about 3%) from the true cruising speed.

COMPARISON OF THE EQUATIONS FOR RANGE AND ENDURANCE

Equation (1) may be written in the form

$$R=B_R\left(\frac{L}{D}\right)\left(\frac{\eta}{c}\right) \tag{1a}$$

where $B_R = 863.5 \log_{10}\left(\frac{W_0}{W_1}\right)$. B_R is therefore a constant for any given value of (W_0/W_1), or for any given value of (W_f/W_0) where W_f is the fuel load. In a similar manner equation (2) may be written

$$T = B_E\left(\frac{L}{D}\right)\left(\frac{\eta}{c}\right)\frac{1}{V_{c_0}} \tag{2a}$$

where V_{c_0} is the initial crusing speed.

The new equations may also be written in the same form as follows:

GENERAL SERVICE

$$R = K_R\left(\frac{L}{D}\right)\left(\frac{\eta}{c_1}\right) \tag{14a}$$

$$T = K_E\left(\frac{L}{D}\right)\left(\frac{\eta}{c_1}\right)\frac{1}{V_{c_0}} \tag{17a}$$

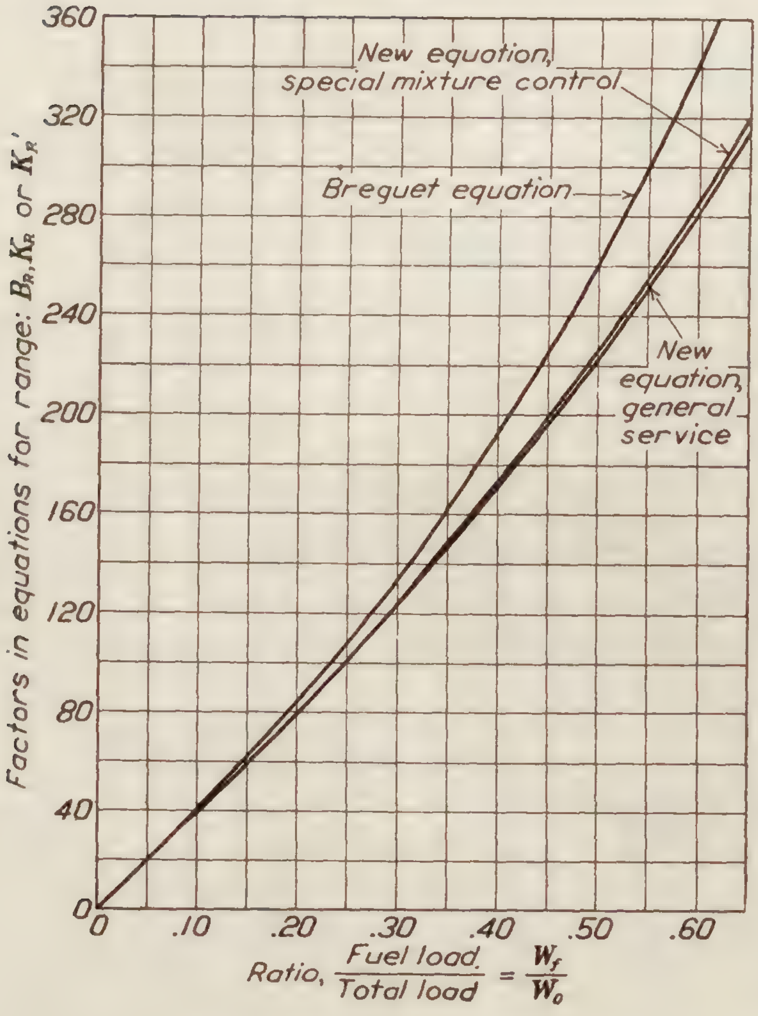


FIG. 3.—Factors in the equations for range

Range=Factor $\left(\frac{L}{D}\right)\left(\frac{\eta}{c}\right)$ miles

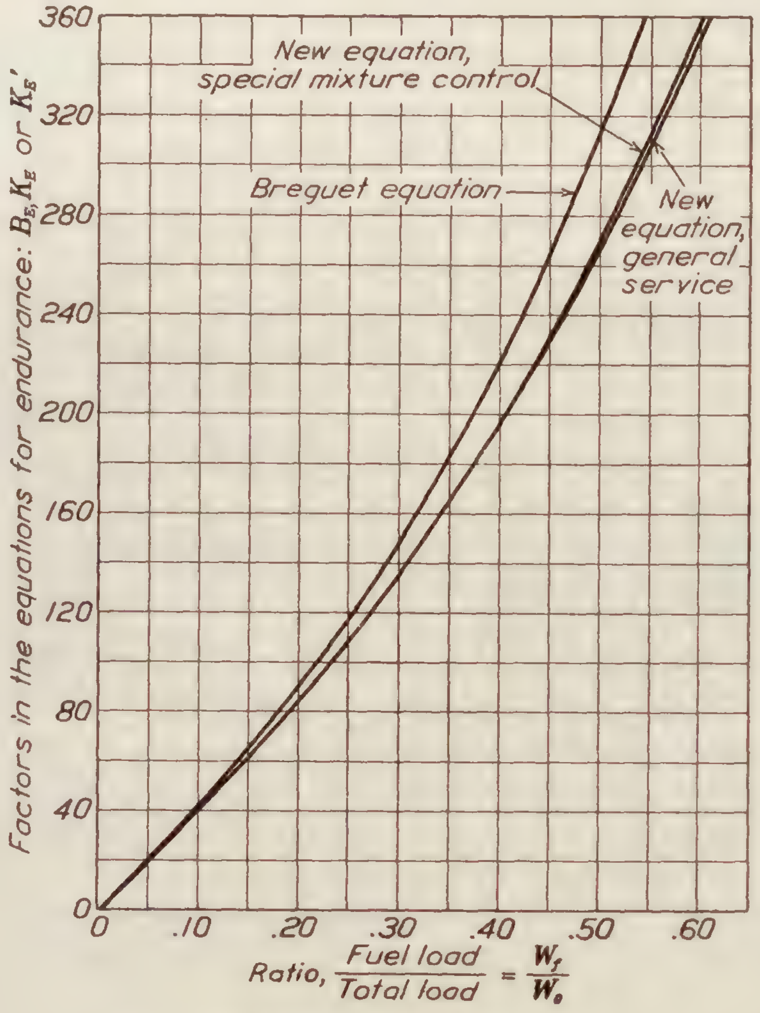


FIG. 4.—Factor in the equations for endurance

Endurance, hrs.$=\frac{\text{Factors}}{Vc_0}\left(\frac{L}{D}\right)\left(\frac{\eta}{c}\right)$ hrs.

SPECIAL MIXTURE CONTROL

$$R = K_R'\left(\frac{L}{D}\right)\left(\frac{\eta}{c_1}\right) \tag{15a}$$

$$T = K_E'\left(\frac{L}{D}\right)\left(\frac{\eta}{c_1}\right)\frac{1}{V_{c_0}} \tag{18a}$$

A comparison is now readily made, since the equations are in the same form. Tables III, IV, V, and VI contain the calculations for the factors B_R, B_E, K_R, K_E, K_R', and K_E'. The factors for range are plotted in Figure 3, and the factors for endurance in Figure 4. It will be seen that the factors for range and endurance in the new equations are but slightly affected by the mixture control, the chief effect of which is therefore to reduce the initial specific fuel consumption. The factors in the Breguet equations are considerably higher than those in the new equations, particularly at high values of the ratio W_f/W_0. This difference is exactly compensated by the higher value of the specific fuel consumption used in the former. It has been pointed out that in equations (1) and (2) or (1a) and (2a), c is the *average value* of the specific fuel consumption for the flight, while in equations (14), (15), (17) and (18), c_1 is the *initial value* of the specific fuel consumption. When c_1 and c are accurately determined by a method to be given later, the two equations give identical results on either range or endurance.

In order that the factors, B_R, B_E, K_R, K_E, K_R', and K_E' may be determined accurately, Table VII has been prepared to give directly the desired factor for any value of W_f/W_0 likely to be used.

AVERAGE CRUISING SPEED

Equations (14a) and (17a) or (15a) and (18a) supply a simple method for determining the ratio of the average cruising speed to the initial cruising speed, (V_c average)/V_{c_0}. This ratio is obviously the ratio K_R/K_E or K_R'/K_E'. Since it is frequently required, it has been calculated in Tables V and VI and plotted in Figure 5.

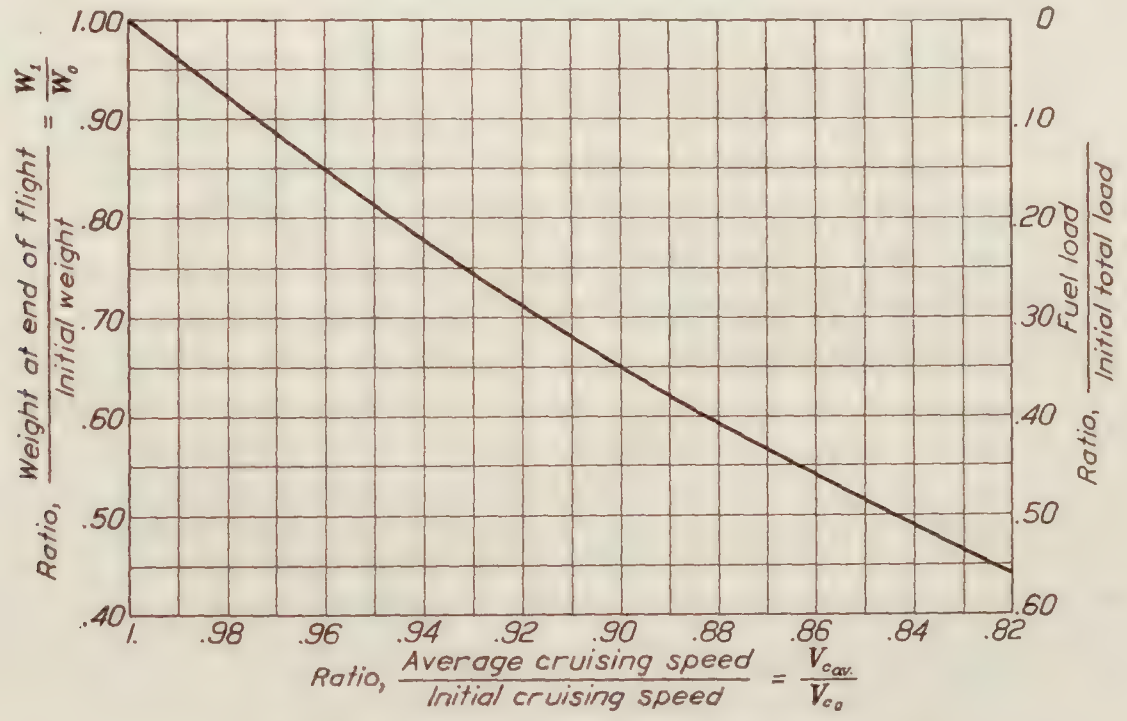


FIG. 5.—Average cruising speed variation with fuel load

THE FACTOR METHOD OF CALCULATING RANGE AND ENDURANCE

The "factor method" of calculating range and endurance was developed by the writer for routine estimating work in the Bureau of Aeronautics. Briefly stated, the method consists of a determination of the factors F_R and F_E where

$$F_R = \text{Ratio } \frac{\text{Range at cruising speed}}{\text{Range at high speed}}$$

and

$$F_E = \text{Ratio } \frac{\text{Endurance at cruising speed}}{\text{Endurance at high speed}}$$

While this method has no outstanding general advantages over the simplified equations given in this report, it is particularly adapted to certain kinds of performance estimating on account of its simplicity and directness. Since the method is entirely new its derivation will be given in full.

It may be shown by theory or flight test data that for an *average* airplane the variation of maximum speed with gross load is very small. This means that the maximum speed will remain substantially constant during a flight in which the fuel load is consumed. Consequently the endurance (T_m) at maximum speed is equal to the fuel load (W_f) divided by the hourly fuel consumption (W_f/T_m) of the engine or engines, at full power and full throttle. The hourly fuel consumption at full throttle is obviously the product of the specific fuel consumption c_0 by the maximum brake horsepower B.HP.$_m$. The range at high speed is equal to the product of the maximum speed by the endurance at maximum speed.

An analysis of test data, both model and free flight, shows the cruising speed V_c to bear a substantially constant relation to the stalling speed V_s with an average value of $V_c = 1.40\ V_s$. This means that regardless of the high speed, or the speed range ratio,[1] except as they affect the propeller efficiency and fuel consumption, the cruising speed depends only on the stalling speed. Since at high speeds the power required for horizontal flight varies substantially as the cube of the speed it should be possible to express the thrust power at any speed greater than cruising speed in terms of the thrust power at cruising speed, and this ratio should show little variation from one airplane to another. Table VII contains the ratios of thrust power at speed V to thrust power at speed V_{CR} for 10 representative airplanes as obtained from wind tunnel test data. The averages of these values form a composite or "average thrust power" curve against speed range ratio as plotted in Figure 6. This thrust power curve gives directly the ratio of the thrust power at high speed to the thrust power at cruising speed.

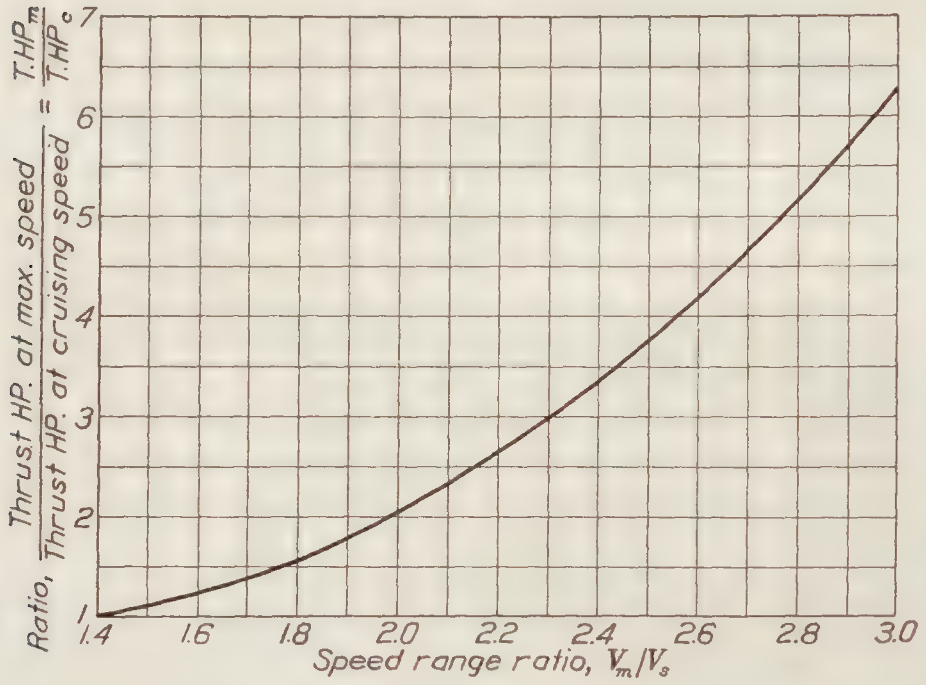


FIG. 6.—Thrust horsepower composite curve

In order to convert the thrust power ratios to brake power ratios the propeller efficiency ratios must be determined. This may readily be done by means of Durand's power coefficient $C_2 = \frac{P}{\rho V^3 D^2}$. Multiplying by the propeller efficiency gives $\eta C_2 = C_2' = \frac{\eta P}{\rho V^3 D^2}$, where ηP is the thrust power in ft. lb. per sec. That is, $C_2' = 550$ T.HP.$/\rho V^3 D^2$. Since T.HP. varies substantially as N^3 over that part of the power-required curve under consideration:

$$C_2' \propto \frac{N^3}{V^3} \propto \left(\frac{V}{ND}\right)^{-3} \tag{19}$$

The ratio of C_2' at maximum and cruising speeds is

$$\frac{(C_2')_m}{(C_2')_c} = \frac{550\ (\text{T.HP.})_m}{\rho V^3_m D^2} \times \frac{\rho V_c^3 D^2}{550\ (\text{T.HP.})_c} = \frac{\text{T.HP.}_m}{\text{T.HP.}_c} \times \left(\frac{V_c}{V_m}\right)^3 \tag{20}$$

From equation (19) the ratio of $\left(\frac{V}{ND}\right)$ at maximum and cruising speeds is

$$\frac{\left(\frac{V}{ND}\right)_m}{\left(\frac{V}{ND}\right)_c} = \left[\frac{(C_2')_d}{(C_2')_m}\right]^{1/3} \tag{21}$$

Given any value of $\left(\frac{V}{ND}\right)_c \Big/ \left(\frac{V}{ND}\right)_m$ the corresponding ratio of the propeller efficiencies η_c/η_m, is readily found from the general efficiency curve of N. A. C. A. Technical Report No. 168 (Reference 2). The ratio of brake horsepower at cruising speed to the maximum brake horsepower is

$$\frac{\text{B.HP.}_c}{\text{B.HP.}_m} = \frac{\text{T.HP.}_c}{\text{T.HP.}_m} \frac{\eta_m}{\eta_c} \tag{22}$$

---

[1] Provided that the initial value of the speed range ratio is greater than 1.4.

Table IX contains calculations for $\text{B.HP.}_c/\text{B.HP.}_m$.

The endurance factor, F_E, is found from

$$F_E=\frac{\text{B.HP.}_m}{\text{B.HP.}_c}\left(\frac{c_0}{c}\right) \tag{23}$$

and the range factor, F_R, from

$$F_R=F_E\left(\frac{V_c}{V_m}\right) \tag{24}$$

Table X contains the calculations for F_E and F_R which are plotted in Figures 7 and 8

APPLICATION OF RANGE AND ENDURANCE FACTORS

In order to use the factor method of calculating range and endurance at cruising speed, the following data must be available:

(1) Maximum speed, V_m, M.P.H.
(2) Stalling speed, V_s M.P.H. for initial and final gross loads.

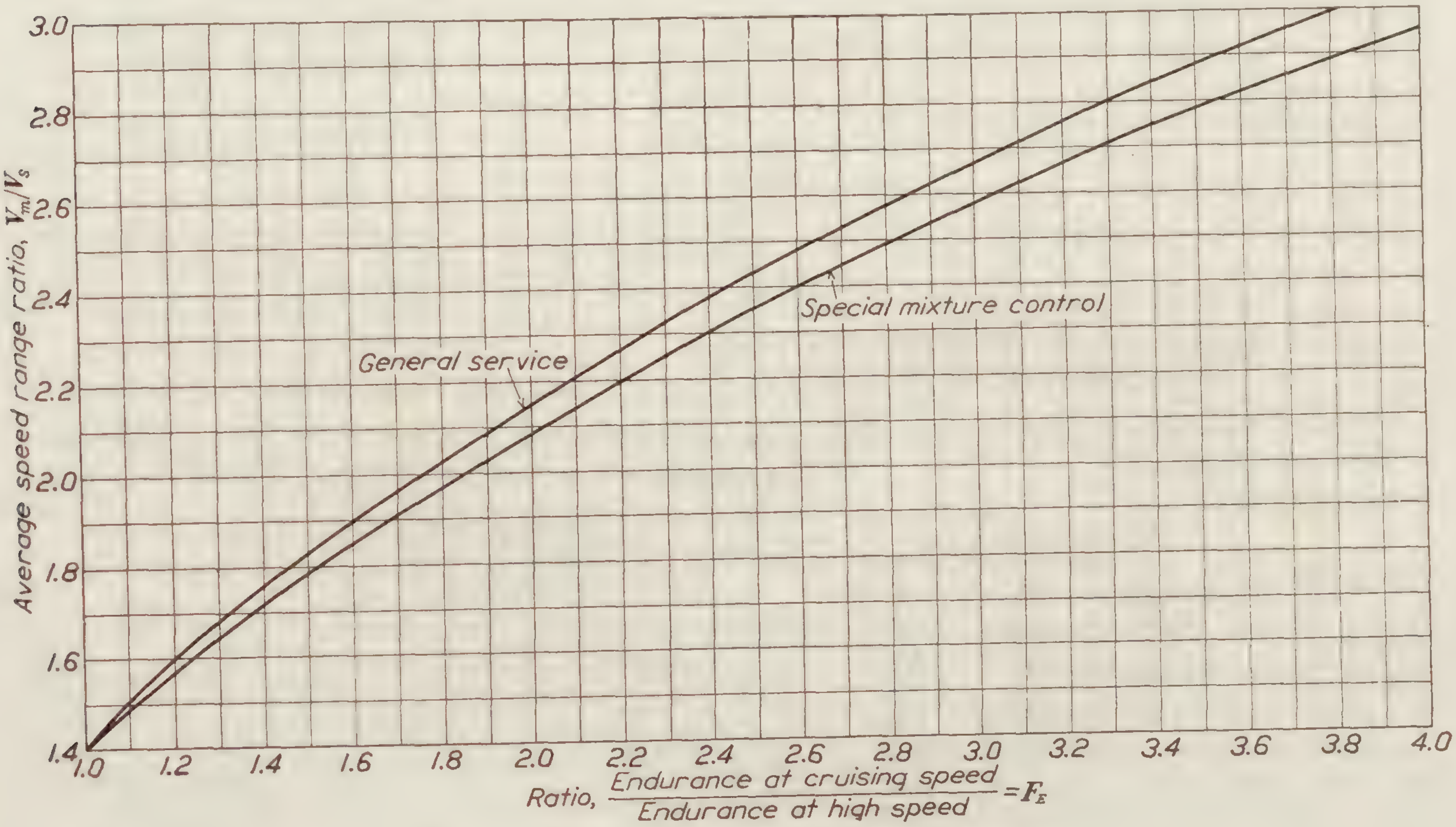


FIG. 7.—Variation with speed range ratio. Endurance factor, F_E

(3) B.HP. at full throttle $=\text{B.HP.}_m$.
(4) Specific fuel consumption at full throttle, c_0 lb./B.HP./hr.
(5) Fuel load, W_f lb.

The steps in applying the method are as follows:

I. Find the hourly fuel consumption at full throttle $\left(\frac{W_f}{T_m}\right)=\left(\text{B.HP.}_m\right)$ c_0 lb./hr.

II. Find endurance at maximum speed $T_m=$ fuel load divided by hourly fuel consumption $=W_f\div\left(\frac{W_f}{T_m}\right)$.

III. Find range at maximum speed $R_m=$ endurance at maximum speed × maximum speed $=T_mV_m$.

IV. Find the average speed range ratio, $(V_m/V_s)_{av}$ and read corresponding endurance and range factors F_E and F_R from Figures 7 and 8.

V. Endurance at cruising speed, $T_c=$ endurance factor × endurance at maximum speed $=F_ET_m$.

VI. Range at cruising speed, R_c = range factor × range at maximum speed = $F_R R_m$.

The average speed range ratio is the average of the speed range ratios for initial gross load and for final gross load. The final gross load W_1 is the initial gross load W_0 less the fuel load W_f. The maximum speed is assumed constant and the stalling speed is determined either from wind tunnel test data or from direct calculation. It is usually satisfactory to take the value of V_s determined by the gross load, wing area, and maximum lift coefficient of the wing section.

Should an airplane be so heavily loaded that its initial speed range ratio is less than 1.4, the high speed will probably increase considerably with decrease in load. In this case an accurate value of the average speed range ratio can be obtained by plotting the speed range ratio against gross weight and integrating the area under the curve.

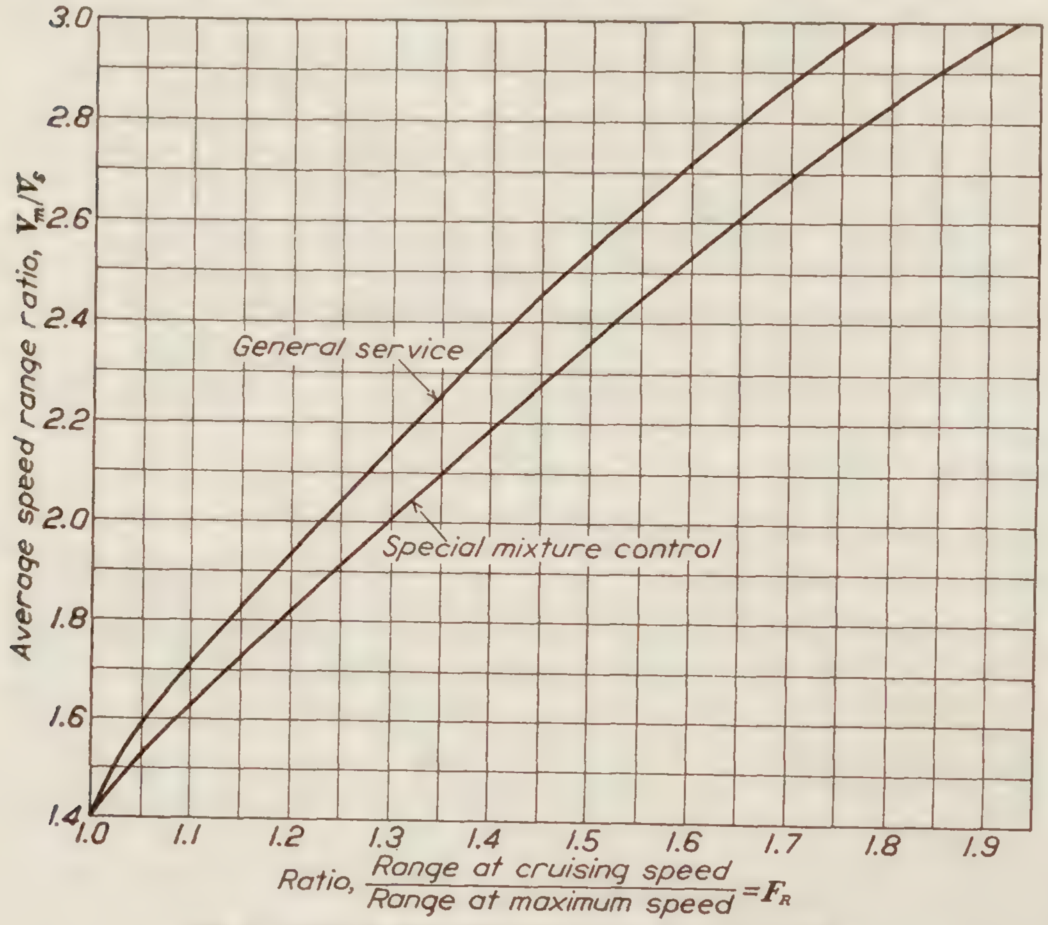


FIG. 8.—Variation with speed range ratio. Range factor, F_R

SPECIFIC FUEL CONSUMPTION AT CRUISING SPEED

The calculations of Table IX supply data for determining the specific fuel consumption at cruising speed, required in using the range and endurance formulas. Figure 9 contains plots of the ratio

$$\frac{\text{specific fuel consumption at cruising speed}}{\text{specific fuel consumption at maximum speed}}$$

against the speed range ratio, V_m/V_s, for the two conditions designated as "General service" and "Special mixture control."

In using these curves with Breguet's equations (1a) and (2a) in which the specific fuel consumption c is an average value. The average value of the speed range ratio V_m/V_s must be determined from the initial and final gross loads. The value of (c/c_0) or (c'/c_0') corresponding to the average value of (V_m/V_s) is then read from Figure 9. This value of (c/c_0) is then multiplied by the specific fuel consumption at full throttle, c_0, to obtain the average specific fuel consumption at cruising speed.

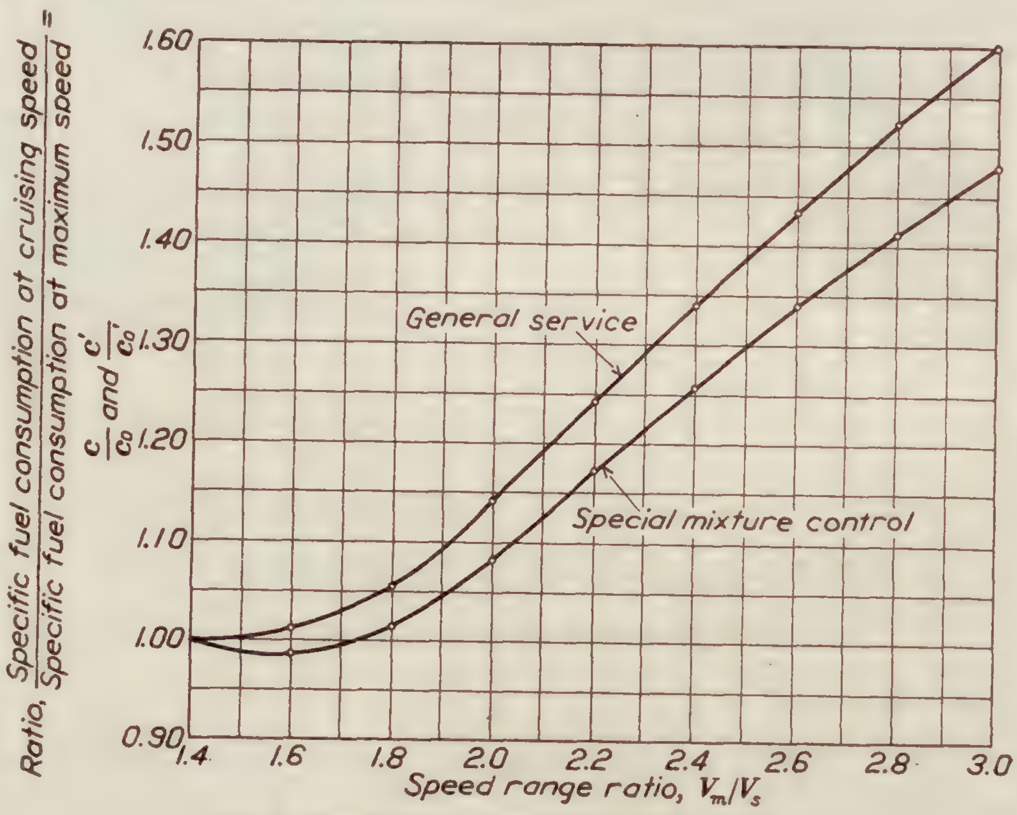


FIG. 9.—Specific fuel consumption at cruising speed

In using the curves with the new equations (14a), (15a), (17a), and (18a) in which the specific fuel consumption c_1 is the initial value, the speed range ratio is determined for the initial condition only. The value of c/c_0 [or (c'/c'_0)] corresponding to the initial value of V_m/V_s is then used in the same manner as the average value was used in Breguet's equations.

COMPARATIVE ESTIMATES

Consider a flying boat having the following characteristics:

Initial gross weight, $W_0 = 16{,}500$ lbs.
Final gross weight, $W_1 = 10{,}500$ lbs.
Fuel load, $W_f = 6{,}000$ lbs.
Maximum B.HP. $= 1{,}020$
Compression ratio $= 5.7$
Maximum propeller efficiency, $\eta_m = .78$
Maximum $(L/D) = 8.48$
Maximum speed $(V_m) = 116$ M.P.H.
Stalling speed, initial, $V_s = 61.6$
Stalling speed, final, $V_s = 49.2$
Stalling speed, average, $V_s = 55.4$

From which—

Initial specific fuel consumption $c_0 = .522$ lb./B.HP./hr. $W_f/W_0 = .364$
Speed range ratio, initial, $(V_m/V_s) = 1.885$
Speed range ratio, final, $(V_m/V_s) = 2.361$
Speed range ratio, average, $(V_m/V_s) = 2.123$

Estimates for cruising range and endurance by the various methods are as follows:

I. BREGUET'S FORMULAS

For $W_f/W_0 = .364$ $B_R = 169.1$ and $B_E = 190.2$.
For the average $V_m/V_s = 2.123$ $c/c_0 = 1.205$ (fig. 9).
$\therefore$ $c = 1.205 \times .522 = .630$ lb./B.HP./hr.
Initial cruising speed $= 1.4 \times 61.6 = 86.2$.

$$\therefore \text{ Range} = 169.1 \times 8.48 \times \frac{.78}{.63} = 1{,}775 \text{ miles.}$$

and

$$\text{Endurance} = 190.2 \times 8.48 \times \frac{.78}{.63} \times \frac{1}{86.2} = 23.2 \text{ hours.}$$

II. NEW FORMULAS

For $W_f/W_0 = .364$ $K_R = 153.3$ and $K_E = 171.5$.
For initial $V_m/V_s = 1.885$ $c/c_0 = 1.086$ (fig. 9).
$\therefore$ Initial $c_1 = 1.086 \times .522 = .569$ lb./B.HP./hr.

$$\therefore \text{ Range} = 153.3 \times 8.48 \times \frac{.78}{.569} = 1{,}780 \text{ miles.}$$

and

$$\text{Endurance} = 171.5 \times 8.48 \times \frac{.78}{.569} \times \frac{1}{86.2} = 23.1 \text{ hours.}$$

III. FACTOR METHOD

Fuel per hr. $= 1{,}020 \times .522 = 533$ lb.

$$\text{Endurance at full throttle} = \frac{6000}{533} = 11.25.$$

Range at maximum speed $= 11.25 \times 116 = 1{,}306$.
For average $(V_m/V_s) = 2.123$, $F_R = 1.29$, $F_E = 1.965$.
Range $= 1.29 \times 1306 = 1{,}690$ miles.
Endurance $= 1.965 \times 11.25 = 22.1$ hours.
A step-by-step integration of the flight gives
Cruising range $= 1{,}739$ miles.
Cruising endurance $= 22.0$ hours.

The comparative values are as follows:

	Breguet's formulas	New formulas	Factor method	Step-by-step integration
Cruising range	1, 775	1, 780	1, 690	1, 739
Cruising endurance	23. 2	23. 1	22. 1	22. 0

From this comparison it is to be concluded that the three methods give results which are well within the limits of error of the known data.

TABLE I

BUREAU OF AERONAUTICS STANDARD FUEL CONSUMPTION DATA FOR THROTTLED CONDITIONS

R.P.M.	Specific fuel consumption ratio		$\frac{B.HP.}{B.HP._0}$ $\left(\frac{R.P.M.}{1,800}\right)^3$	$\frac{B.HP._0}{B.HP.}$
	General service	Special mixture control		
1,800	1. 000	1. 000	1. 000	1. 000
1, 700	1. 008	. 983	. 8423	1. 1872
1, 600	1. 037	1. 000	. 7024	1. 4237
1, 500	1. 090	1. 040	. 5787	1. 728
1, 400	1. 163	1. 100	. 4705	2. 1254
1, 300	1. 250	1. 180	. 3767	2. 6546
1, 200	1. 352	1. 266	. 2963	3. 375
1, 100	1. 463	1. 363	. 2282	4. 382
1, 000	1. 586	1. 463	. 1715	5. 831
900	1. 712	1. 565	. 1250	8. 000

TABLE II

VARIATION OF SPECIFIC FUEL CONSUMPTION WITH COMPRESSION RATIO

Compression ratio	Specific fuel consumption lb./B.HP./hr.
C. R.	c_0
4. 6	0. 566
4. 8	. 558
5. 0	. 550
5. 2	. 542
5. 4	. 534
5. 6	. 526
5. 8	. 518
6. 0	. 510
6. 2	. 502
6. 4	. 494
6. 6	. 486
6. 8	. 478
7. 0	. 470

$c_0=0.75-0.04\ C.\ R.$

TABLE III

CALCULATION OF CONSTANT B_R IN BREGUET'S FORMULA FOR RANGE

$$\text{Range}=863.47\,\frac{\eta}{c}\left(\frac{L}{D}\right)\log_{10}\left(\frac{W_0}{W_1}\right)=B_R\,\frac{\eta}{c}\left(\frac{L}{D}\right)\text{ Miles.}$$

$\frac{W_1}{W_0}$	$\frac{W_0}{W_1}$	$\log_{10}\left(\frac{W_0}{W_1}\right)$	B_R $863.47\log_{10}\left(\frac{W_0}{W_1}\right)$
1. 000	1. 000	0	0
. 90	1. 1111	. 0457574	39. 510
. 85	1. 17647	. 0705811	60. 945
. 80	1. 2500	. 0969100	83. 679
. 75	1. 3333	. 1249388	107. 881
. 70	1. 42857	. 1549019	133. 752
. 65	1. 53846	. 1870868	161. 544
. 60	1. 66667	. 2218488	191. 560
. 55	1. 818182	. 2596373	224. 189
. 50	2. 000000	. 3010300	259. 930
. 45	2. 222220	. 3467875	299. 441
. 40	2. 500000	. 3979400	343. 609

TABLE IV

CALCULATION OF CONSTANT B_E IN BREGUET'S FORMULA FOR ENDURANCE

$$\text{Endurance}=\frac{750}{Vc_0}\,\frac{\eta}{c}\left(\frac{L}{D}\right)\left(\frac{1}{\sqrt{K}}-1\right)=\frac{B_E}{Vc_0}\,\frac{\eta}{c}\left(\frac{L}{D}\right)\text{hours.}$$

$\frac{W_1}{W_0}$ K	$\sqrt{K}$	$\frac{1}{\sqrt{K}}$	$\frac{1}{\sqrt{K}}-1$	B_E $750\left(\frac{1}{\sqrt{K}}-1\right)$
1. 00	1. 000	1. 000	0	0
. 90	. 94868	1. 05409	. 05409	40. 570
. 85	. 92195	1. 08465	. 08465	63. 490
. 80	. 89443	1. 11803	. 11803	88. 523
. 75	. 86603	1. 15470	. 15470	116. 025
. 70	. 83666	1. 19523	. 19523	146. 423
. 65	. 80623	1. 24035	. 24035	180. 263
. 60	. 77460	1. 29099	. 29099	218. 243
. 55	. 74162	1. 34840	. 34840	261. 300
. 50	. 70711	1. 41421	. 41421	310. 658
. 45	. 67082	1. 49071	. 49071	368. 033
. 40	. 63246	1. 58114	. 58114	435. 855

TABLE V

CALCULATION OF CONSTANTS IN NEW FORMULAS FOR RANGE AND ENDURANCE

GENERAL SERVICE

$\frac{W_1}{W_0}$	Range			Endurance			$\frac{K_R}{K_E}$
	$\left(\frac{W_1}{W_0}\right)^{.45}$	$1-\left(\frac{W_1}{W_0}\right)^{.45}$	K_R	$\left(\frac{W_0}{W_1}\right)^{.05}$	$\left(\frac{W_0}{W_1}\right)^{.05}-1$	K_E	
1.00	1.00	0	0	1	0	0	1.00
.90	.95369	.04631	38.590	1.005282	.005282	39.615	.9741
.85	.92948	.07052	58.767	1.008159	.008159	61.193	.9604
.80	.90446	.09554	79.617	1.011220	.011220	84.150	.9461
.75	.87857	.12143	101.192	1.014488	.014488	108.660	.9313
.70	.85171	.14829	123.575	1.017994	.017994	134.955	.9157
.65	.82378	.17622	146.850	1.021773	.021773	163.297	.8993
.60	.79464	.20536	171.133	1.025870	.025870	194.025	.8820
.55	.76412	.23588	196.567	1.030343	.030343	227.573	.8638
.50	.73204	.26796	223.300	1.035265	.035265	264.488	.8443
.45	.69814	.30186	251.550	1.040733	.040733	305.498	.8234
.40	.66211	.33789	281.575	1.046880	.046880	351.600	.8008

$$\text{Range} = K_R \frac{\eta}{c_1}\left(\frac{L}{D}\right) \text{ miles.}$$

$$\text{Endurance} = \frac{K_E}{Vc_0}\frac{\eta}{c_1}\left(\frac{L}{D}\right) \text{ hours.}$$

$$\text{Average cruising speed} = \frac{K_R}{K_E} \times \text{initial cruising speed.}$$

TABLE VI

CALCULATION OF CONSTANTS IN NEW FORMULAS FOR RANGE AND ENDURANCE

SPECIAL MIXTURE CONTROL

$\frac{W_1}{W_0}$	Range			Endurance			$\frac{K'_R}{K'_E}$
	$\left(\frac{W_1}{W_0}\right)^{.42}$	$1-\left(\frac{W_1}{W_0}\right)^{.45}$	K'_R	$\left(\frac{W_0}{W_1}\right)^{.08}$	$\left(\frac{W_0}{W_1}\right)^{.08}-1$	K'_E	
1.00	1.000	0	0	1.00	0	0	1.00
.90	.95671	.04329	38.652	1.008464	.008464	39.675	.9742
.85	.93402	.06598	58.911	1.013086	.013086	61.341	.9604
.80	.91054	.08946	79.875	1.018012	.018012	84.431	.9460
.75	.88619	.11381	101.616	1.023281	.023281	109.130	.9311
.70	.86088	.13912	124.214	1.028945	.028945	135.680	.9155
.65	.83449	.16551	147.777	1.035063	.035063	164.358	.8991
.60	.80691	.19309	172.402	1.041712	.041712	195.525	.8817
.55	.77795	.22205	198.259	1.048989	.048989	229.636	.8634
.50	.74742	.25258	225.518	1.057018	.057018	267.272	.8437
.45	.71507	.28493	254.402	1.065965	.065965	309.211	.8227
.40	.68056	.31944	285.214	1.076057	.076057	356.517	.8000

$$\text{Range} = K'_R \frac{\eta}{c_1}\left(\frac{L}{D}\right) \text{ miles.}$$

$$\text{Endurance} = \frac{K'_E}{Vc_0}\frac{\eta}{c_1}\left(\frac{L}{D}\right)$$

$$\text{Average cruising speed} = \frac{K'_R}{K'_E} \times \text{initial cruising speed.}$$

TABLE VII

CONSTANTS IN THE EQUATIONS FOR RANGE AND ENDURANCE

$\frac{W_f}{W_0}$	Breguet's equations		New equations			
			General service		Special-mixture control	
	Range	Endurance	Range	Endurance	Range	Endurance
	B_R	B_E	K_R	K_E	K'_R	K'_E
0.01	3.8	3.8	3.8	3.8	3.8	3.8
.02	7.6	7.6	7.5	7.6	7.5	7.6
.03	11.4	11.5	11.3	11.4	11.3	11.4
.04	15.3	15.4	15.2	15.3	15.2	15.3
.05	19.2	19.4	19.0	19.3	19.0	19.3
.06	23.2	23.5	22.9	23.2	22.9	23.3
.07	27.2	27.7	26.8	27.3	26.8	27.3
.08	31.3	31.9	30.7	31.3	30.7	31.4
.09	35.4	36.2	34.6	35.5	34.7	35.5
.10	39.5	40.6	38.6	39.6	38.7	39.7
.11	43.7	45.0	42.6	43.8	42.7	43.9
.12	47.9	49.5	46.6	48.1	46.7	48.2
.13	52.2	54.1	50.6	52.4	50.7	52.5
.14	56.6	58.8	54.7	56.8	54.8	56.9
.15	61.0	63.5	58.8	61.2	58.9	61.3
.16	65.4	68.3	62.9	65.7	63.1	65.8
.17	69.9	73.2	67.0	70.2	67.2	70.4
.18	74.4	78.2	71.2	74.8	71.4	75.0
.19	79.0	83.3	75.4	79.4	75.6	79.7
.20	83.7	88.5	79.6	84.2	79.9	84.4
.21	88.4	93.8	83.9	88.9	84.2	89.2
.22	93.2	99.2	88.2	93.8	88.5	94.1
.23	98.0	104.7	92.5	98.7	92.8	99.1
.24	102.9	110.3	96.8	103.6	97.2	104.1
.25	107.9	116.0	101.2	108.7	101.6	109.1
.26	112.9	121.9	105.6	113.8	106.1	114.3
.27	118.0	127.8	110.0	119.0	110.6	119.5
.28	123.2	133.9	114.5	124.2	115.1	124.8
.29	128.4	140.1	119.0	129.6	119.6	130.2
.30	133.8	146.4	123.6	135.0	124.2	135.7
.31	139.1	152.9	128.2	140.5	128.9	141.2
.32	144.6	159.5	132.8	146.0	133.5	146.9
.33	150.2	166.3	137.4	151.7	138.2	152.6
.34	155.8	173.2	142.1	157.5	143.0	158.4
.35	161.5	180.3	146.9	163.3	147.8	164.4
.36	167.4	187.5	151.6	169.3	152.6	170.4
.37	173.3	194.9	156.4	175.3	157.5	176.5
.38	179.3	202.5	161.3	181.4	162.4	182.7
.39	185.4	210.3	166.2	187.7	167.4	189.1
.40	191.6	218.2	171.1	194.0	172.4	195.5
.41	197.9	226.4	176.1	200.5	177.5	202.1
.42	204.3	234.8	181.2	207.1	182.6	208.8
.43	210.8	243.5	186.3	213.8	187.8	215.6
.44	217.4	252.3	191.4	220.6	193.0	222.6
.45	224.2	261.3	196.6	227.6	198.3	229.6
.46	231.1	270.6	201.8	234.7	203.6	236.9
.47	238.1	280.2	207.1	241.9	209.0	244.2
.48	245.2	290.1	212.4	249.3	214.4	251.8
.49	252.5	300.2	217.8	256.8	220.0	259.4
.50	259.9	310.7	223.3	264.5	225.5	267.3
.51	267.5	321.4	228.8	272.3	231.2	275.3
.52	275.2	332.5	234.4	280.4	236.9	283.5
.53	283.1	344.0	240.0	288.6	242.6	291.9
.54	291.2	355.8	245.8	297.0	248.5	300.4
.55	299.4	368.0	251.6	305.5	254.4	309.2
.56	307.9	380.7	257.4	314.3	260.4	318.2
.57	316.5	393.8	263.3	323.3	266.5	327.4
.58	325.3	407.3	269.3	332.5	272.6	336.9
.59	334.4	421.4	275.4	341.9	278.9	346.6
.60	343.6	435.9	281.6	351.6	285.2	356.5

NOTE:

$$\text{Range miles} = B_R\left(\frac{L}{D}\right)\left(\frac{\eta}{c}\right) \quad \text{Breguet's equation.}$$

$$= K_R\left(\frac{L}{D}\right)\left(\frac{\eta}{c_1}\right) \quad \text{New equation—General service.}$$

$$= K'_R\left(\frac{L}{D}\right)\left(\frac{\eta}{c_1}\right) \quad \text{New equation—Special-mixture control.}$$

$$\text{Endurance, hours} = \frac{B_E}{V_{c_0}}\left(\frac{L}{D}\right)\left(\frac{\eta}{c}\right) \quad \text{Breguet's equation.}$$

$$= \frac{K_E}{V_{c_0}}\left(\frac{L}{D}\right)\left(\frac{\eta}{c_1}\right) \quad \text{New equation—General service.}$$

$$= \frac{K'_E}{V_{c_0}}\left(\frac{L}{D}\right)\left(\frac{\eta}{c_1}\right) \quad \text{New equation—Special-mixture control.}$$

$$\frac{W_f}{W_0} = \text{Ratio } \frac{\text{Weight of fuel}}{\text{Initial gross load}}.$$

TABLE VIII

VARIATION IN T. HP. REQUIRED ASSUMING CRUISING SPEED=1.40 V_s

$\frac{V}{V_s}$	VE-7	PB-1	D-27	D-26	DH-4	CS-1	MO-1	TG	TS	EM	Average
1.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.6	1.25	1.22	1.24	1.23	1.30	1.22	1.22	1.16	1.24	1.17	1.225
1.8	1.65	1.59	1.56	1.56	1.68	1.56	1.53	1.46	1.58	1.48	1.565
2.0	2.15	2.08	1.99	2.03	2.18	2.01	1.95	1.94	2.06	1.97	2.036
2.2	2.86	2.71	2.55	2.57	2.91	2.62	2.46	2.54	2.64	2.59	2.645
2.4	3.48	3.44	3.26	3.27	3.70	3.28	3.06	3.34	3.29	3.27	3.339
2.6	4.25	4.27	4.10	4.15	4.65	4.02	3.84	4.44	4.12	4.02	4.186
2.8	5.10	5.29	5.21	5.15	5.75	4.90	4.72	5.24	5.06	4.93	5.135
3.0	6.18	6.36	6.33	6.59	7.00	5.90	5.65	6.75	6.14	5.98	6.288

TABLE IX

CRUISING B.HP. IN TERMS OF MAXIMUM B. HP.

$\frac{V_m}{V_s}$	$\frac{V_m}{V_c}$	$\frac{\text{T.HP.}_m}{\text{T.HP.}_c}$	$\frac{(c_2')_c}{(c_2')_m}$	$\frac{\left(\frac{V}{ND_c}\right)}{\left(\frac{V}{ND_m}\right)}$	$\frac{\eta_c}{\eta_m}$	$\frac{\text{B.HP.}_m}{\text{B.HP.}_c}$	$\frac{\text{B.HP.}}{\text{B.HP.}_m}$	Specific fuel consumption ratio	
	$\frac{V_m}{1.4\,V_s}$	From Figure 6	See note 1	See note 2	See note 3	See note 4		General service	Special mixture control
								$\frac{c}{c_0}$	$\frac{c'}{c'_0}$
1.4	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1.6	1.143	1.225	1.218	.936	.997	1.221	.819	1.012	.984
1.8	1.286	1.565	1.360	.903	.988	1.546	.647	1.055	1.014
2.0	1.429	2.036	1.433	.888	.984	2.003	.499	1.141	1.082
2.2	1.571	2.645	1.467	.880	.981	2.595	.385	1.241	1.172
2.4	1.714	3.339	1.508	.872	.978	3.266	.306	1.340	1.258
2.6	1.857	4.186	1.538	.866	.976	4.086	.245	1.434	1.340
2.8	2.000	5.135	1.558	.863	.975	5.007	.200	1.522	1.412
3.0	2.143	6.288	1.570	.860	.974	6.125	.163	1.605	1.480

NOTES:

(1) $\frac{(c_2')_c}{(c_2')_m} = \frac{\text{T.HP.}_c}{\text{T.HP.}_m} \times \left(\frac{V_m}{V_c}\right)^3$

(2) $\frac{\left(\frac{V}{ND}\right)_c}{\left(\frac{V}{ND}\right)_m} = \left[\frac{(c_2')_c}{(c_2')_m}\right]^{-1/3}$

(3) $\frac{\eta_c}{\eta_m}$ is from the general efficiency curve in N. A. C. A. Technical Note No. 168.

(4) $\frac{\text{B.HP.}_m}{\text{B.HP.}_c} = \frac{\text{T.HP.}_m}{\text{T.HP.}_c} \times \frac{\eta_c}{\eta_m}$

TABLE X

CALCULATION OF RANGE AND ENDURANCE FACTORS

$\frac{V_m}{V_s}$	$\frac{V_m}{V_c}$	$\frac{B.HP._m}{B.HP._c}$	$\frac{c}{c_0}$	General service		Special mixture control		
				Endurance factor F_E	Range factor F_R	$\frac{c'}{c_0'}$	Endurance factor F_E'	Range factor F_R'
1.4	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1.6	1.143	1.221	1.012	1.206	1.055	.984	1.241	1.086
1.8	1.286	1.546	1.055	1.465	1.139	1.014	1.525	1.186
2.0	1.429	2.003	1.141	1.755	1.228	1.082	1.852	1.295
2.2	1.571	2.595	1.241	2.092	1.333	1.172	2.213	1.409
2.4	1.714	3.266	1.340	2.437	1.421	1.258	2.596	1.514
2.6	1.857	4.086	1.434	2.849	1.534	1.340	3.049	1.642
2.8	2.000	5.007	1.522	3.290	1.645	1.412	3.546	1.773
3.0	2.143	6.125	1.605	3.816	1.780	1.480	4.139	1.931

$$F_E = \text{Ratio } \frac{\text{Endurance at cruising speed}}{\text{Endurance at maximum speed}} = \frac{B.HP._m}{B.HP._c} \frac{c_0}{\ }$$

$$F_R = \text{Ratio } \frac{\text{Range at cruising speed}}{\text{Range at maximum speed}} = F_E \frac{V_c}{V_m}$$

REFERENCES

1. J. G. Coffin: A Study of Airplane Ranges and Useful Loads. N. A. C. A. Technical Report No. 69—1920.
2. Walter S. Diehl: Reliable Formulæ for Estimating Airplane Performance and the Effects of Changes in Weight, Wing Area, or Power. N. A. C. A. Technical Report No. 173—1925.
3. Walter S. Diehl: The General Efficiency Curve for Air Propellers. N. A. C. A. Technical Report No. 168—1923.

REPORT No. 235

INTERACTION BETWEEN AIR PROPELLERS AND AIRPLANE STRUCTURES

By W. F. DURAND
Leland Stanford Junior University, California

REPORT No. 235

INTERACTION BETWEEN AIR PROPELLERS AND AIRPLANE STRUCTURES

By W. F. Durand

INTRODUCTION

This investigation was conducted at the Stanford University by the National Advisory Committee for Aeronautics at the request of and with funds provided by the Army Air Service.

The purpose of the investigation, the results of which are presented in this report, was the determination of the character and amount of interaction between air propellers as usually mounted on airplanes and the adjacent parts of the airplane structure—or, more specifically, those parts of the airplane structure within the wash of the propeller, and capable of producing any significant effect on propeller performance.

In report No. 177, by Messrs. Lesley and Woods, such interaction between air propellers and certain simple geometrical forms was made the subject of investigation and report. The present investigation aims to carry this general study one stage further by substituting actual airplane structures for the simple geometrical forms.

From the point of view of the present investigation, the airplane structures, viewed as an obstruction in the wake of the propeller, must also be viewed as a necessary part of the airplane and not as an appendage which might be installed or removed at will.

ANALYSIS OF PROBLEM

In order to exhibit the quantities involved and their mutual relations, we may employ notation as follows:

Let R = resistance of entire airplane without propeller at speed V, and in horizontal unaccelerated flight. This is similar to the towed resistance used in similar problems in ship propulsion. It would be, in fact, the *towed* resistance if we could imagine the given airplane towed through still air at speed V.

Let the structure of the airplane be considered under three heads:

(1) The part under the influence of the propeller.

(2) A small or moderate amount of outlying structure, beyond that in the immediate wash of the propeller.

(3) The remainder of the airplane.

Let R_1 = resistance due to Part (1) without the propeller and at speed V.
R_2 = resistance due to Part (2) at speed V.
R_3 = resistance due to Part (3) at speed V.

Then $R = R_1 + R_2 + R_3$.

Let A = augmentation of resistance of Part (1) due to action of propeller.
T = thrust actually developed by propeller at air speed V and with a given value of V/nD and when operating in place on the airplane.

Then T is the total thrust actually developed by the airplane under operative conditions as above and we shall have

$$T = R_1 + A + R_2 + R_3 \qquad (1)$$

We may therefore view this total T as made up of two parts

$R_1+R_2+R_3$ = net or useful resistance overcome.

A = augmentation due to action of propeller on the airplane.

Obviously then, $T-A=R_1+R_2+R_3$ = useful resistance overcome . . . . (2)

Likewise

$$A=(R_1+R_2+R_3+A)-(R_1+R_2+R_3)$$

or

$$A=(R_1+R_2+A)-(R_1+R_2) \tag{3}$$

Also $(T-A)V$ = useful power.

Let Q = torque.

Then $2\pi\, nQ$ = shaft or input power.

$$\text{Propulsive efficiency} = \eta_1 = \frac{(T-A)V}{2\pi\, nQ} \tag{4}$$

This value compared with the value of η for the propeller operating in free air, and with the same value of V/nD, will then give a comparison between the propulsive efficiency and the free air efficiency for the same conditions of operation (same value of V/nD).

Suppose now a model to be made representing Parts (1) and (2) of the airplane—enough to surely include all parts of the airplane which can interact with the propeller and a little more for good measure. Then with this model and with the corresponding model propeller, let us assume a program of three series of tests as follows:

(1) Wind resistance tests of the model free.

(2) The usual tests of the propeller free, giving for a series of values of V/nD, values of thrust, torque and efficiency.

(3) Tests of the combination, including resistance measurements on the model and the usual measurements on the propeller, all carried out at a series of values of V/nD.

Then for any test under (3) there will be a resultant T with a certain V/nD and a certain V. This is obviously the actual thrust developed under operative conditions. The same test will give likewise a value of (R_1+R_2+A), the augmented resistance of the model. The preceding experiments will have given for the same V the value of (R_1+R_2) the normal free resistance. The difference will give the value of A, the augmentation due to the propeller, and this subtracted from the value of T will give the net or useful thrust realized. This is then used as indicated above, and the value of the propulsive efficiency thus found.

It will now be seen that the division of the structure of the airplane into three parts as above specified was for the purpose of indicating the possibility of eliminating Part (3) from the model and of thus limiting the latter simply to the Parts (1) and (2) as above noted. This makes possible the use of models of relatively large scale with the attendant advantage which such models give, and which are too well known to require special note.

Approaching the matter from a slightly different view point we reach the same result as follows:

Given the model and the propeller in operative relation. The propeller, under specified conditions, develops an actual thrust T. In so doing, however, it has increased the force reaction of the air on the model by the amount A. This amount A must then be deducted from T in order to find the net useful thrust developed for propulsive purposes—the thrust which is equal to the towed resistance of the airplane (complete structure) and which airplane such net thrust $(T-A)$ would serve to propel, could the operation be carried out without any interaction between airplane and propeller. The actual input power under these conditions is then the power which must be supplied to the propeller in order that, operating in front of the airplane, it will develop a total thrust T equal to the free resistance at the given speed plus the amount of augmentation which its operation entails.

From still another view point, suppose we imagine a propeller at the extremity of a shaft, say 1,000 feet long, extended out ahead of the airplane. We may then assume the interaction between the airplane and propeller negligible. Then both propeller and airplane will operate as in free air and the resistance of the latter will be the free air or "towed" resistance as referred to above. Obviously, the propulsive efficiency here will be the same as the propeller efficiency in free air. If then we imagine the shaft to be gradually shortened in, there will begin to develop, in due time, an interaction between the airplane and the propeller, as a result of which both the thrust (pull) developed and the resistance to be overcome will increase. Finally with the propeller in its normal relation to the airplane we shall find a notable increase in both, and if the engine is driven at such speed as will serve to give the same airspeed of the airplane as before, we may consider that the same net useful result is accomplished. This useful power will evidently be $(T-A)\,V$ and the input power to accomplish this will be $2\pi nQ$—the power resulting from the actual n and actual Q. The ratio between the two will then give the propulsive efficiency under the given conditions of operation.

A physical cause for the augment of wind reaction or force on the airplane is found in the augment of velocity of the air in the propeller wash and which flows against the front of the model.

Likewise, a physical cause for the augment of thrust (pull) developed by the propeller is found in the slowing down of the air velocity as it approaches the propeller and in consequence of the obstruction represented by the airplane. With a given value of n, the thrust increases as the airspeed decreases and in consequence, if the central column of air approaching the propeller is slowed down relative to its velocity in the case of the propeller free, the latter will show a corresponding augment of thrust developed.

Certain aspects of the phenomena as observed in the tests covered by the present report suggest that there are other conditions which must be included in order to obtain a complete account of these changes in air reaction and in thrust. At the present time, however, data are not available for any further statement regarding the matter.

MODELS EMPLOYED

In order to realize the purposes as above indicated, three models were constructed as follows:

Model A represents a part of a thick wing section under study by the Army Air Service with reference to its availability for use in a new type of bombing airplane. This model is shown in Figures 1 and 2.

The throat diameter of the wind tunnel at Stanford University is 90 inches and having in view the maximum over-all size of model which it seemed wise to use in a tunnel of this size, it developed that, with the propellers in proportionate size, a diameter of 24 inches was indicated. Accordingly the propellers were made of this diameter, and the model of proportionate size, the wing section of the model extending 6 inches beyond the tip of the blades, and thus having an over-all breadth of 36 inches.

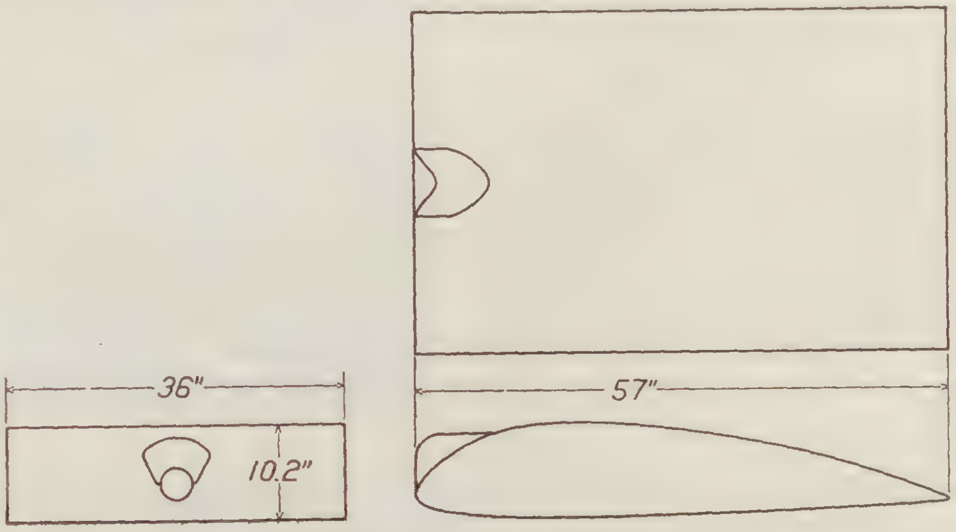


FIG. 1.—Night bomber, type XIII. Model A. Stanford University. (See Drawing M-2102, Air Engineering Division U. S. A.

Model B represents the central power plant installation of the same design as for model A. This model is shown in Figures 3 and 4. The more immediate obstruction in the case of model B is represented by the machine gun turret immediately back of the propeller, by the landing gear a little farther away, and by the wings at a still greater distance. In the case of this model, with the front edges of the wing so far back of the propeller, it was not convenient to carry the wing back the distance of its entire chord. It was therefore carried back in regular form for a part of the way, and then faired down to the trailing edge more abruptly than in the actual design. See dotted lines of Figure 3. This gives a wing of shortened chord as

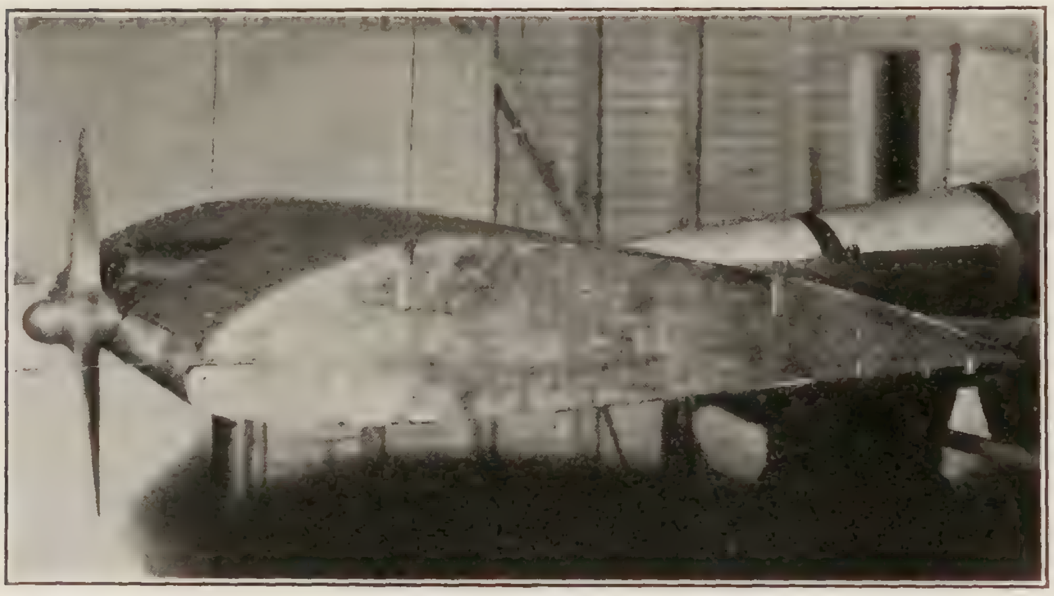


FIG 2.—Model A

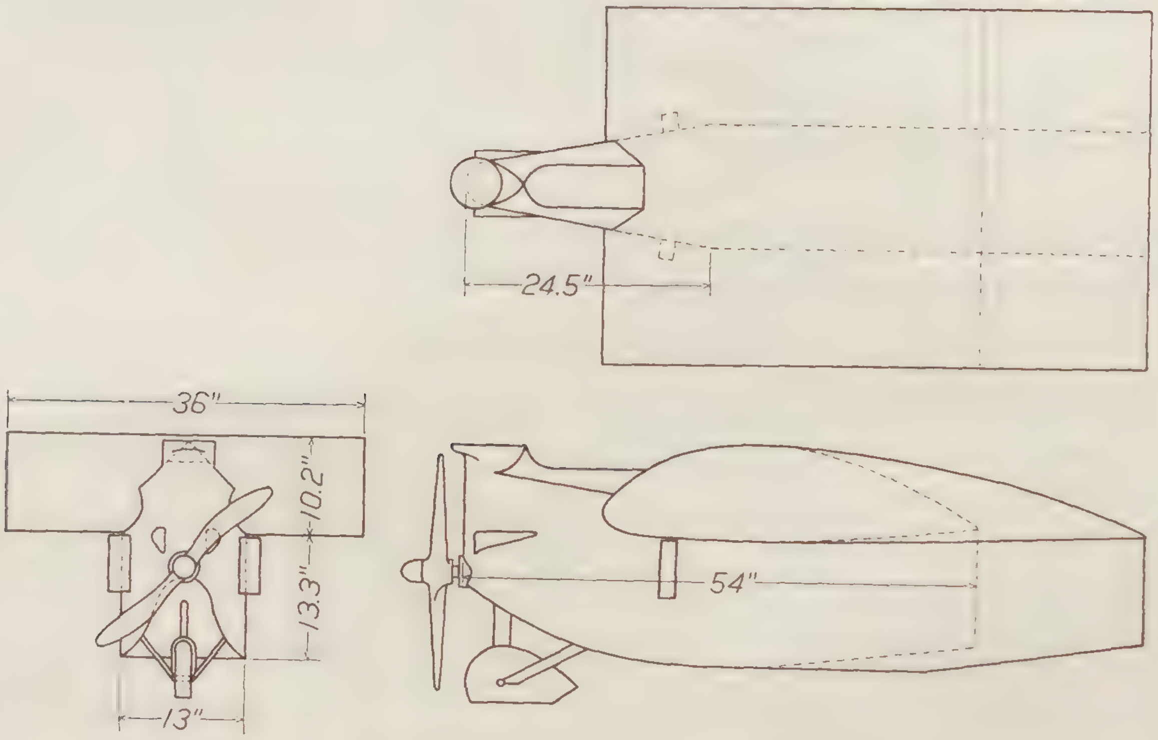


FIG. 3.—Night bomber, type XIII. Model B. Stanford University. (See drawing M-2102, Air Engineering Division U. S. A.)

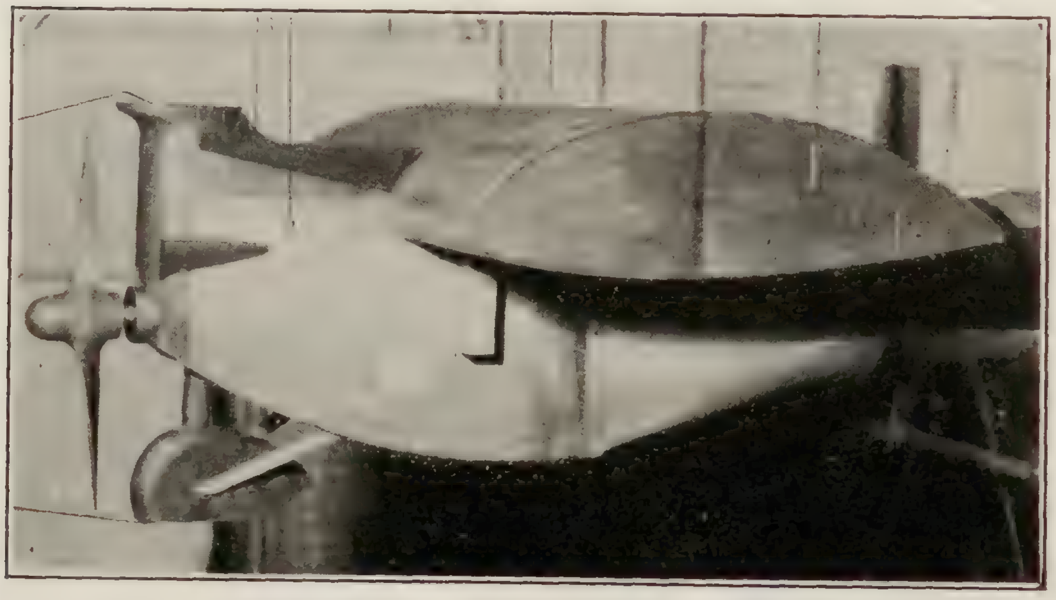


FIG. 4.—Model B

compared with the regular wing of model A. Experience with the character of the reaction between the propeller and the adjacent parts of the structure, and especially with the parts which are most influential in producing such reaction, gives good ground for the belief that such a shortening up of the chord, with the wing as far removed as it is, will have no important influence on the results so far as the propeller is concerned. The aerodynamic properties of the wing would of course be different in themselves, but it is not here a question of the aerodynamic properties in themselves, but rather of the *difference* in such properties produced by the propeller, and of the *difference* in the performance of the propeller produced by the proximity of these structural elements.

Model C represents the front end of the fuselage of the DeHavilland airplane as shown in Figures 5 and 6. In this case, having in view the distance between the propeller and the wings, and in order to simplify the construction of the model, it was decided to omit the wings entirely. While therefore the model does not represent all parts of the airplane within the wash of the propeller, all previous tests with obstructions indicate that in such a design the reaction between airplane and propeller must in preponderant degree be due to the nose of the fuselage rather than to the wings and tail surfaces. The nose of the model was fitted with a wire mesh, 40 spaces per inch, and wire 0.006 inch diameter. This is found to have an air resistance closely comparable to that of an airplane radiator of normal design. In addition and for comparative purposes, the model was also run with the end entirely open, and also blanked off with a sheet of heavy paper.

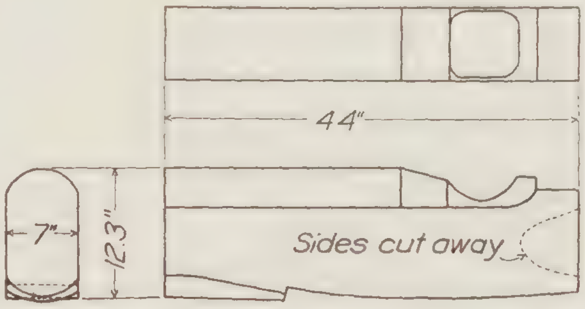


FIG. 5.—DH4 fuselage. Model C. Stanford University. (Fuselage shortened to accommodate dynamometer)

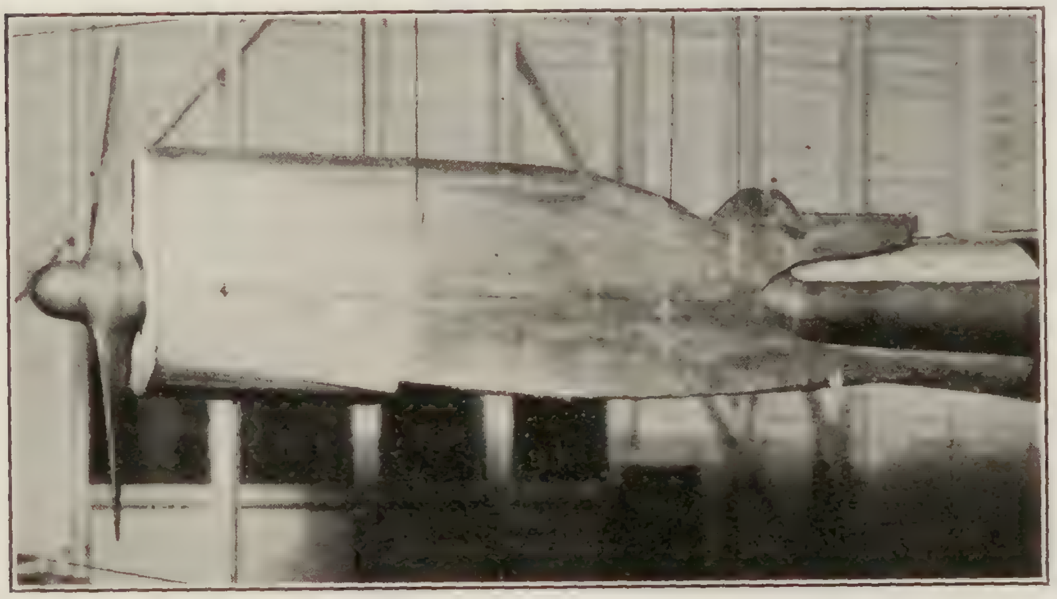


FIG. 6.—Model C

Regarding the lack of complete similarity between airplane and model, or more particularly in models B and C it may be noted that with the construction and set-up of the dynamometer, this was unavoidable. However, a very considerable body of observation with geometrical models as well as the results of the present investigation with different values of the clearance all go to show the very rapid falling off of influence on the propeller with increase of distance between the propeller and the obstructing surface or body. These results all tend to support definitely the conclusion that the influence of surfaces giving generally a frictional drag and at distances of one and one-half diameters of the propeller or more, would produce an effect on the propeller presumably within the error of observation.

Propellers.—The propellers employed were two in number, similar to Nos. 7 and 3 of Report No. 141, and of which the principal characteristics are as follows:

Propeller No. 1, pitch ratio, 0.7.
Propeller No. 2, pitch ratio, 0.9.
Diameter, 24 inches.
Mean blade width, 0.15 r.
Maximum blade width, 0.18 r.

The blade shape (developed) and the forms of sections at radii 2.67, 4.67, 6.67, 8.67, 10.67 inches are shown in Figure 7.

The propellers are similar in all respects except as to pitch ratio. The face pitch is uniform.

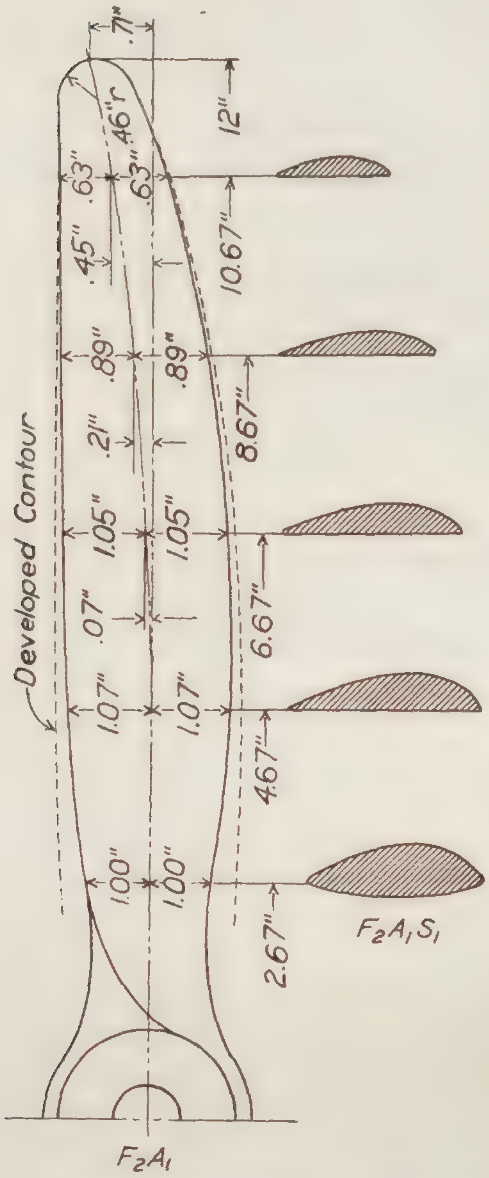


FIG. 7.—Plan form and section of propellers with .7 and .9. p/D

NUMBER OF COMBINATIONS OF SIGNIFICANT ELEMENTS

In the case of models A and B, each model was tested with each propeller and for each of three values of the distance or clearance between the propeller blades and the nearest part of the model. In the case of model C, tests were made with each propeller at each of two values of the distance or clearance between the propeller blades and the fuselage nose, and for each of three conditions or degrees of nose obstruction.

This gives 12 different set-ups with models A and B and 12 with model C, or 24 in all.

SET-UP OF APPARATUS AND MODEL

It may be proper to recall, at this point, that the wind tunnel at Stanford University is of the Eiffel type and with principal dimensions as indicated in Figure 8.

The dynamometer, as indicated in Figure 9, consists essentially of a slender tapering barrel some 9 feet long mounted on knife-edges as a cradle dynamometer and with the model propeller motor located in the larger down-wind end of the barrel, faired in as a part of the barrel form. The motor is connected to the propeller through a special form of drive which transmits torque with longitudinal freedom of propeller shaft. This general arrangement provides for the direct measurement of thrust and torque which are weighed on beam scales, graduated, respectively, in hundredths of kilograms and in thousandths of kilogram-meters.

In order to provide for the independent measure of forces on the propeller model and on the airplane model, the latter was suspended by piano wires from the ceiling of the experiment chamber, the length of suspension being about 7 feet. The model, thus suspended, hangs entirely free of contact with the dynamometer barrel and may be placed in any desired clearance relation with the propeller. This arrangement places the model and the propeller in operative relation geometrically while permitting of independent measure of the forces on each. This arrangement is shown in Figures 2, 4, and 6.

For the direct measurement of air forces on the model a piano-wire bridle was attached to the two sides of the model at shaft level and thus accommodating the propeller between the two sides of the bridle leads. From the apex of the triangle thus formed a single piano wire was led forward (up wind) through the honeycomb baffle, through and beyond the tunnel inlet to the end wall of the building, and over a carefully fitted-up pulley down to a gross weight on the plate of a beam scale weighing to hundredths of a pound. Thus, by subtraction, the pull on the model due to air flow may be directly weighed on the scale.

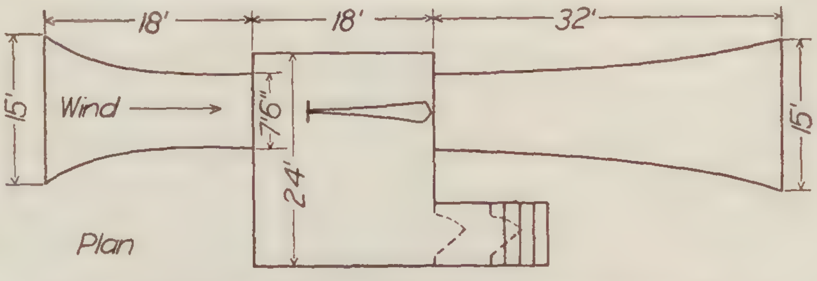


FIG. 8.—Wind tunnel of Stanford University (approximate sketch)

In order, however, that the reading of the scale may be made to indicate air forces and nothing else, it is necessary that the model, when in the observing condition, should hang in the free gravity position; otherwise there will be a gravity component, plus or minus, included in the scale reading. In order to eliminate any such component, the following operative routine was followed:

The model, without wind and disconnected from the piano wire leading to the scale, was allowed to hang freely under gravity and while so hanging a transit instrument, set up abreast of the model and at the side of the experiment chamber, entirely out of the wind stream, was adjusted with vertical cross hair on a reference mark on a paper scale attached to the model. Then, during the observations, the model was brought, by suitable fine motion adjustment, exactly to this initial or zero position, with the mark on the vertical cross hair. Under these conditions the scale readings may be properly interpreted as giving (by subtraction from the gross) the actual wind forces on the model.

It is obvious, furthermore, that this arrangement may be used either with or without the propeller, and thus provide for a measurement of air forces on the model either in a homogeneous air stream or as influenced by the operation of the propeller placed with any desired clearance between itself and the forward edge or plane of the model.

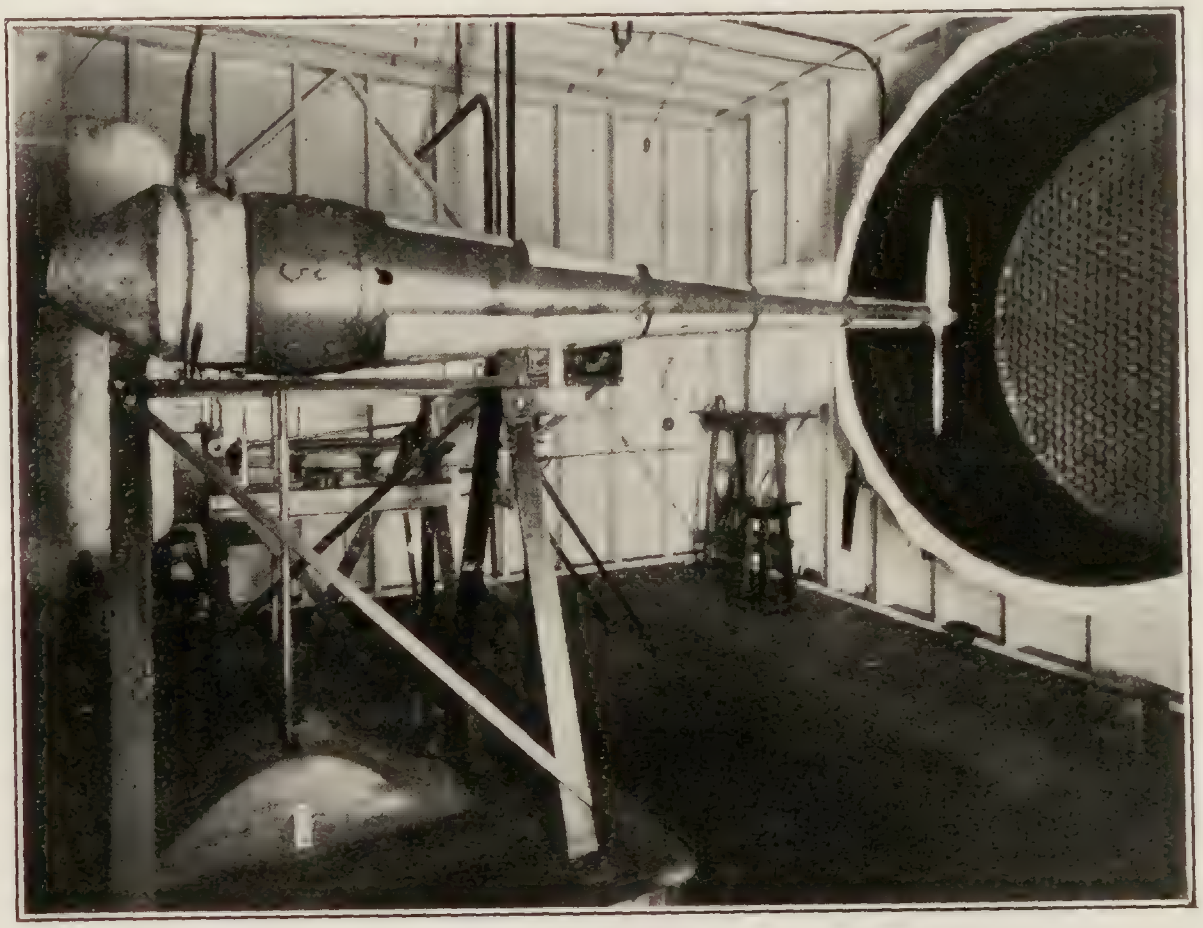


FIG. 9.—General view of dynamometer

OBSERVATIONS

In accordance with the methods indicated in the preceding sections observations were made covering the various elements of the problem. These observations with the resulting values of the various coefficients are given in Tables III to XXVI.

In the reduction of these observations the following coefficients have been employed:

C_T = Thrust coef. (propeller alone) $= \frac{T}{\rho n^2 D^4}$.

C_T = Thrust coef. (propeller with airplane)* $= \frac{(T-A)}{\rho n^2 D^4}$.

C_{P_1} = Power Coef. $= \frac{P}{\rho n^3 D^5}$.

η = Efficiency (propeller alone).

η_1 = Propulsive efficiency (propeller with airplane) $= \frac{C_T}{C_{P_1}} \frac{V}{nD}$.

Also for tabular presentation, the following notation is convenient.

T = Actual thrust.

R_a = Resistance of model with propeller in action.

R_o = Resistance of model without propeller, at same speed as for R_a.

A = Augment of resistance due to propeller $= R_a - R_o$.

C_T = Thrust coef. $= (T-A) \div \rho n^2 D^4$.

C_{P_1} = Power coef. $= P \div \rho n^3 D^5$.

---

* No confusion seems to result from the use of the same symbol C_T for thrust coefficient either with or without airplane. The context will always indicate which condition obtains. When $A=0$ the two values become identical.

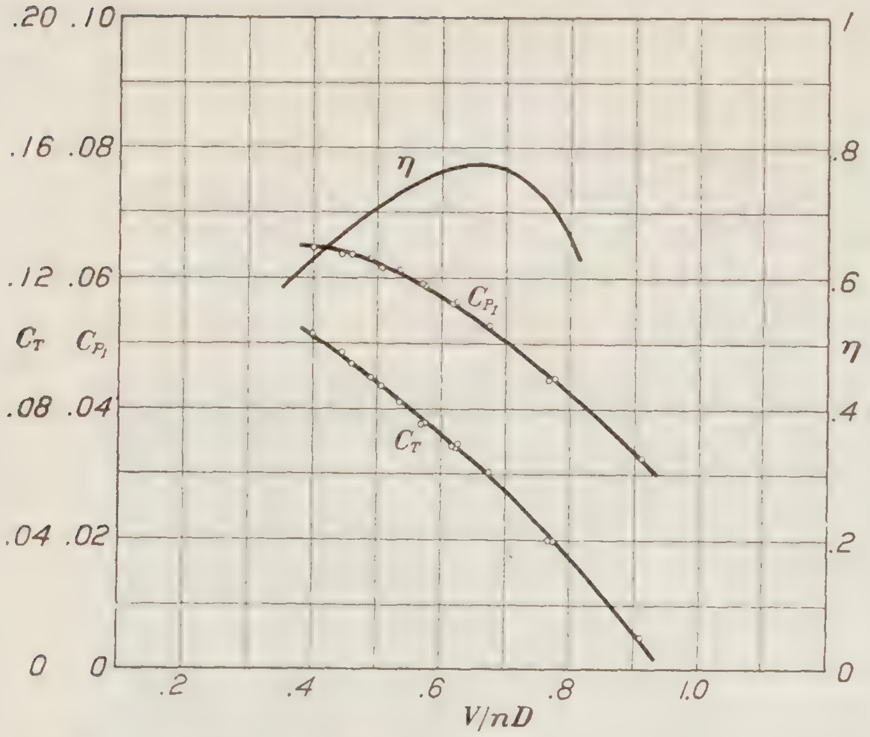


FIG. 10.—Characteristic coefficients of propeller No. 7. Diameter 24 inches. Nominal pitch ratio .7

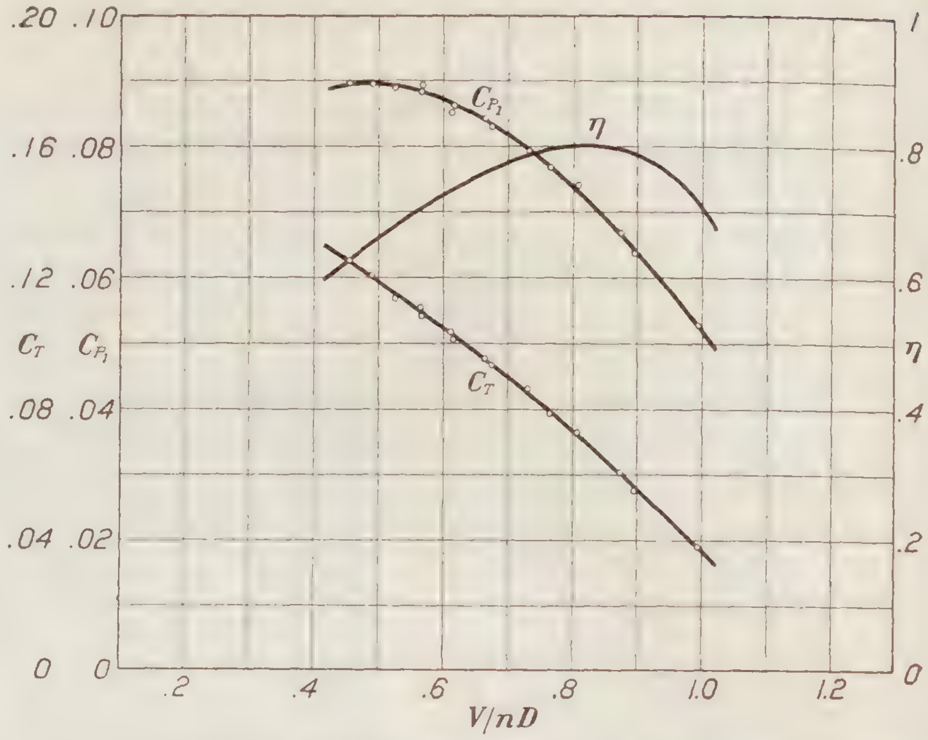


FIG. 11.—Characteristic coefficients of propeller No. 2. Diameter 24 inches. Nominal pitch ratio 9.

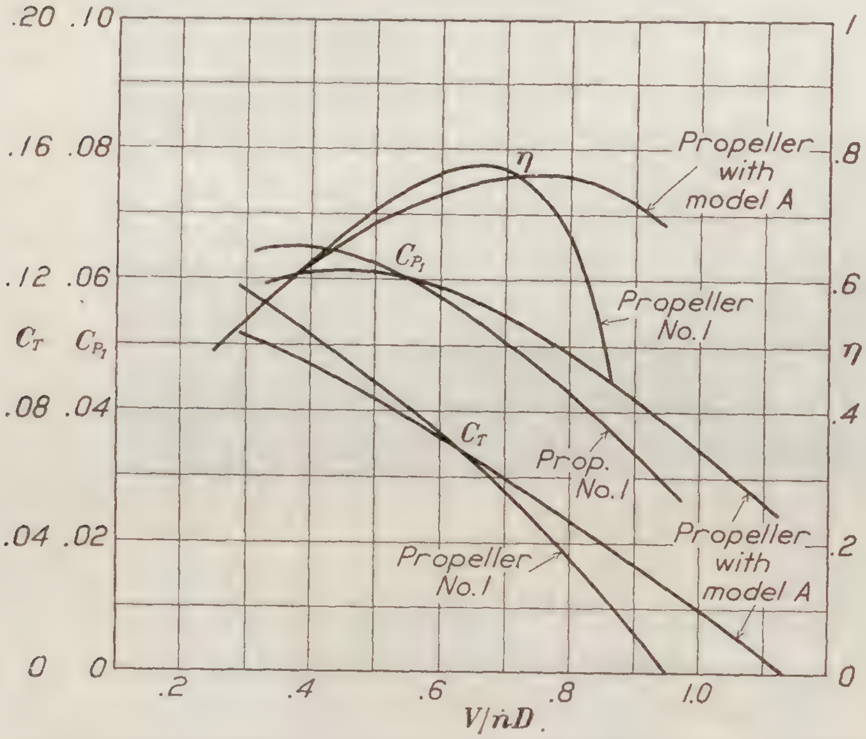


FIG. 12.—Typical effect of slip stream obstruction on propeller coefficients. Propeller No. 1. Unobstructed. Propeller No. 1 with model A at 4 inch clearance

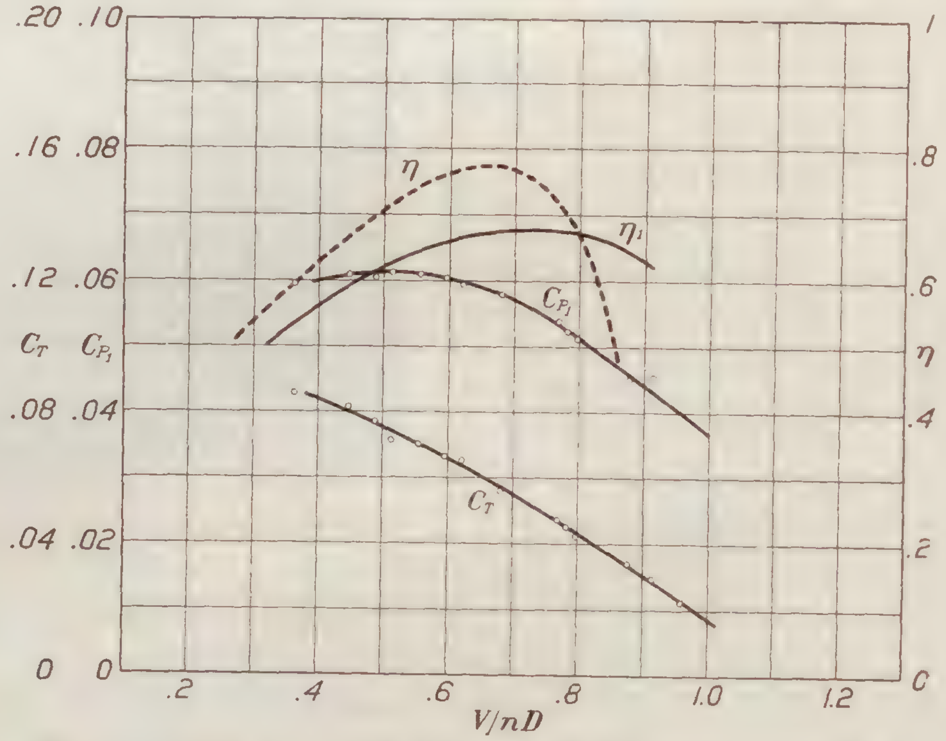


FIG. 13.—Propeller No. 1. Pitch ratio .7. Model A—wing clearance 0.375 inch

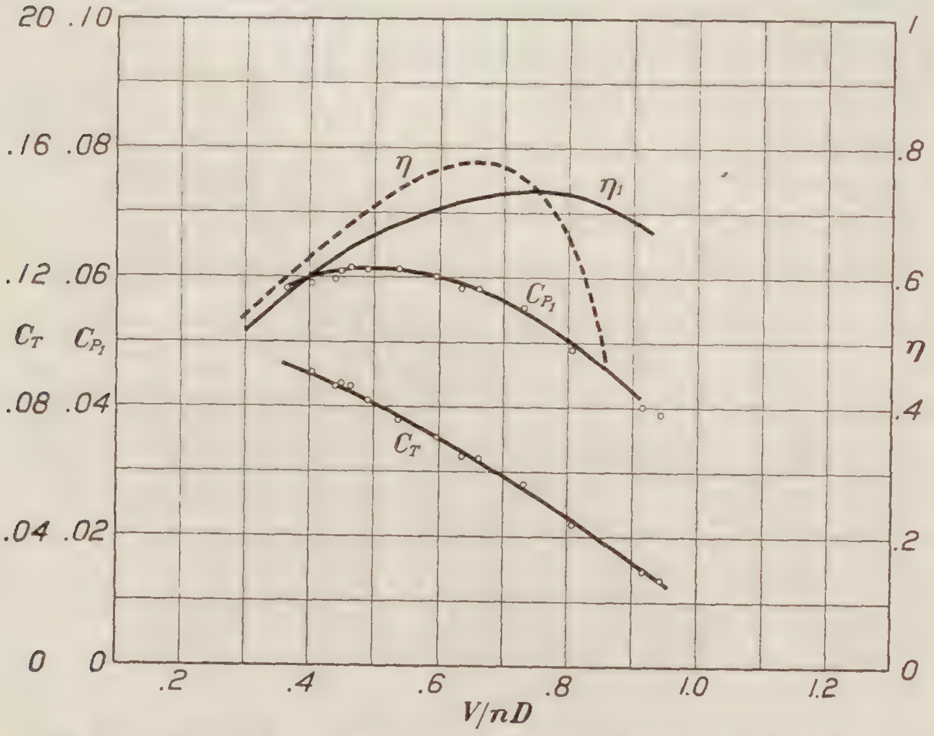


FIG. 14.—Propeller No. 1. Pitch ratio .7. Model 1—wing clearance 2 inches

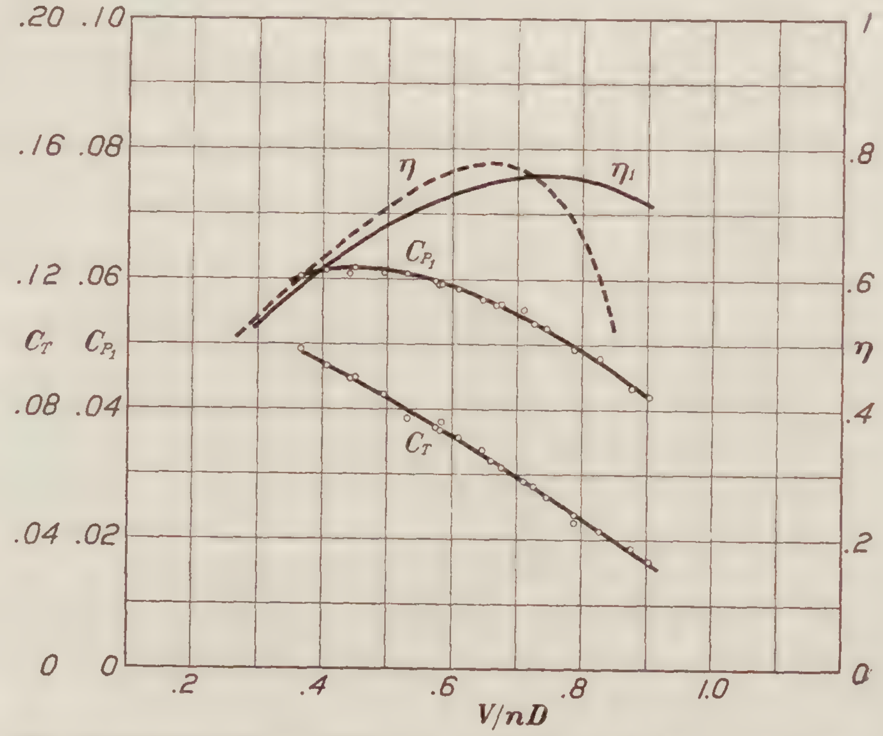


FIG. 15.—Propeller No. 1. Pitch ratio .7. Model A—wing clearance 4 inches

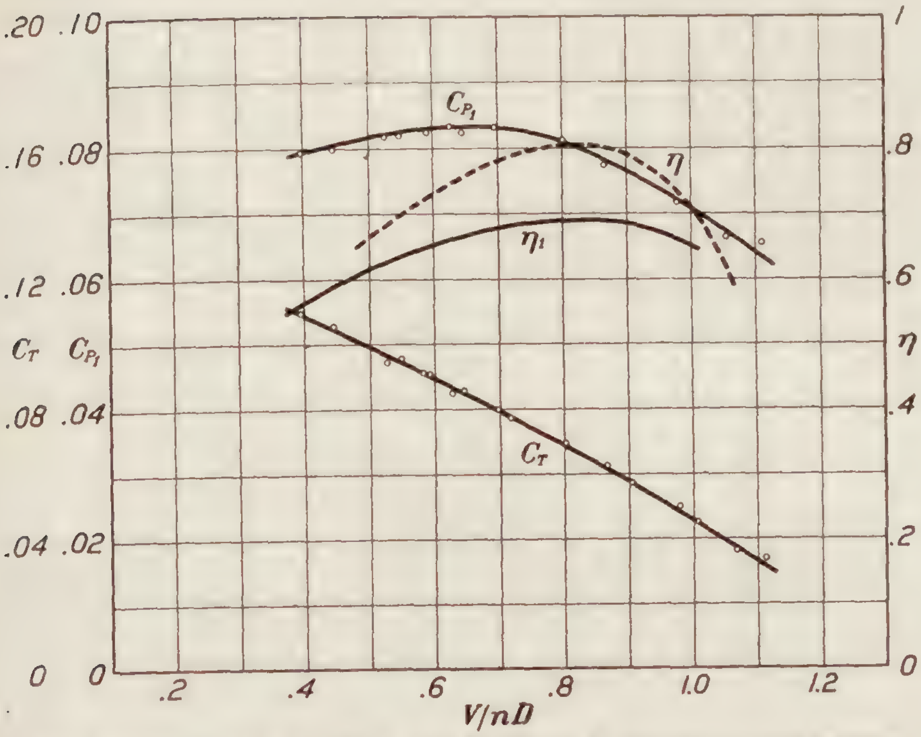


FIG. 16.—Propeller No. 2. Pitch ratio .9. Model A—wing clearance 0.375 inch

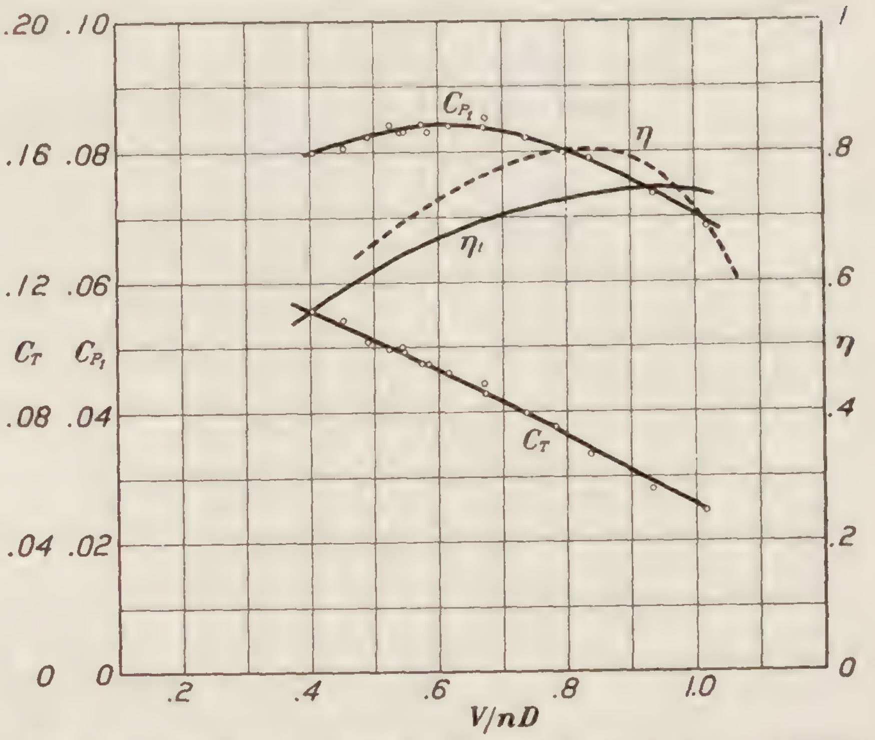


FIG. 17.—Propeller No. 2. Pitch ratio 9. Model A—wing clearance 2 inches

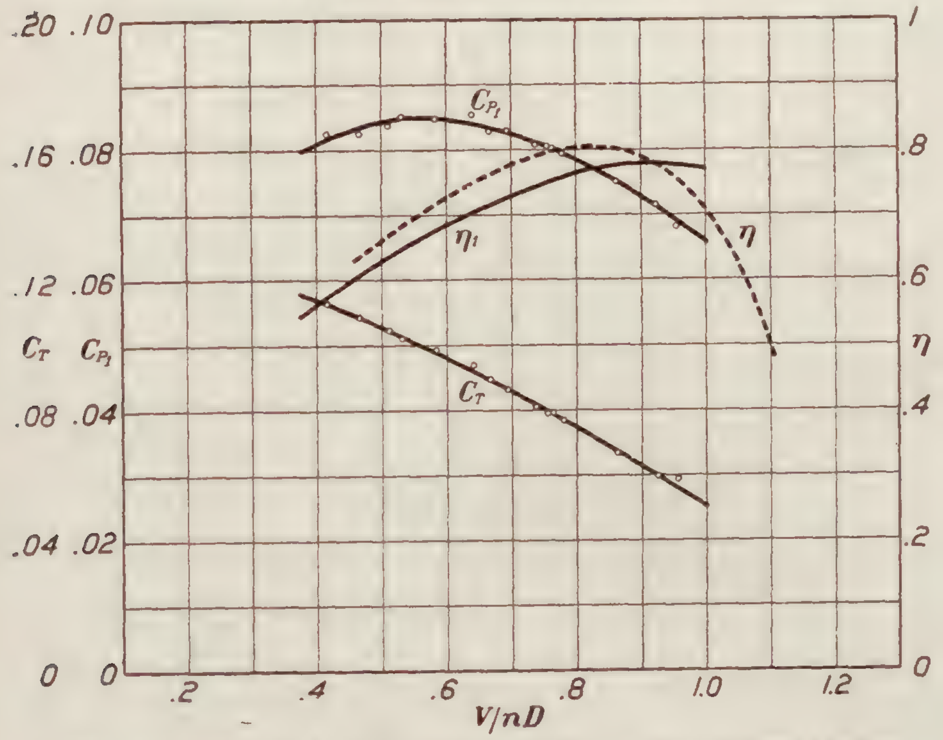


FIG. 18.—Propeller No. 2. Pitch ratio .9. Model A—wing clearance 4 inches

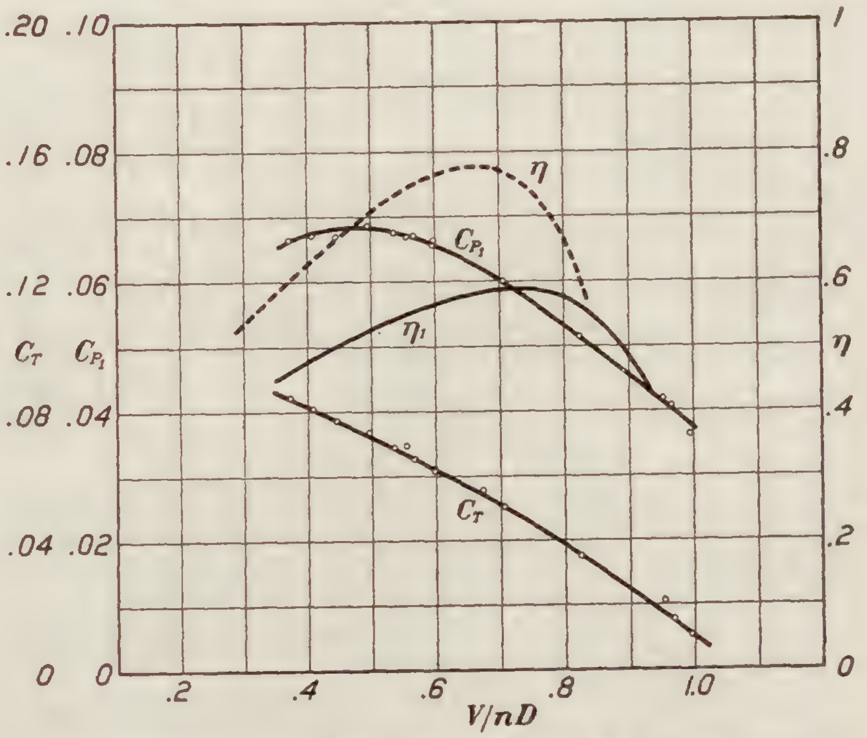


FIG. 19.—Propeller No. 1. Pitch ratio .7. Model B—fuselage clearance 0.375 inch

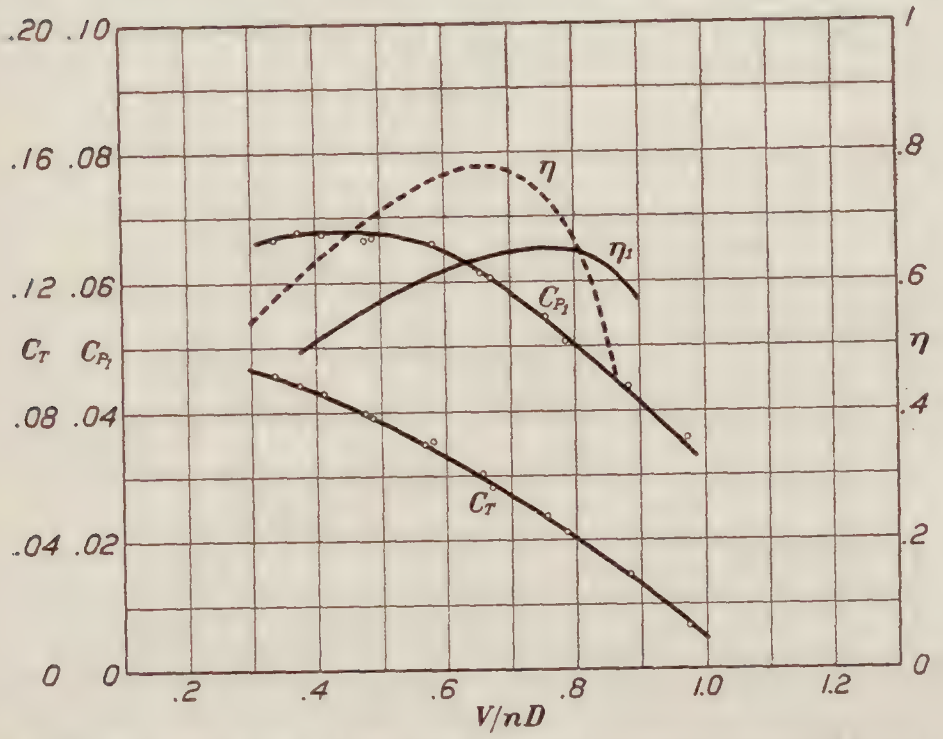


FIG. 20.—Propeller No. 1. Pitch ratio .7. Model B—fuselage clearance 2 inches

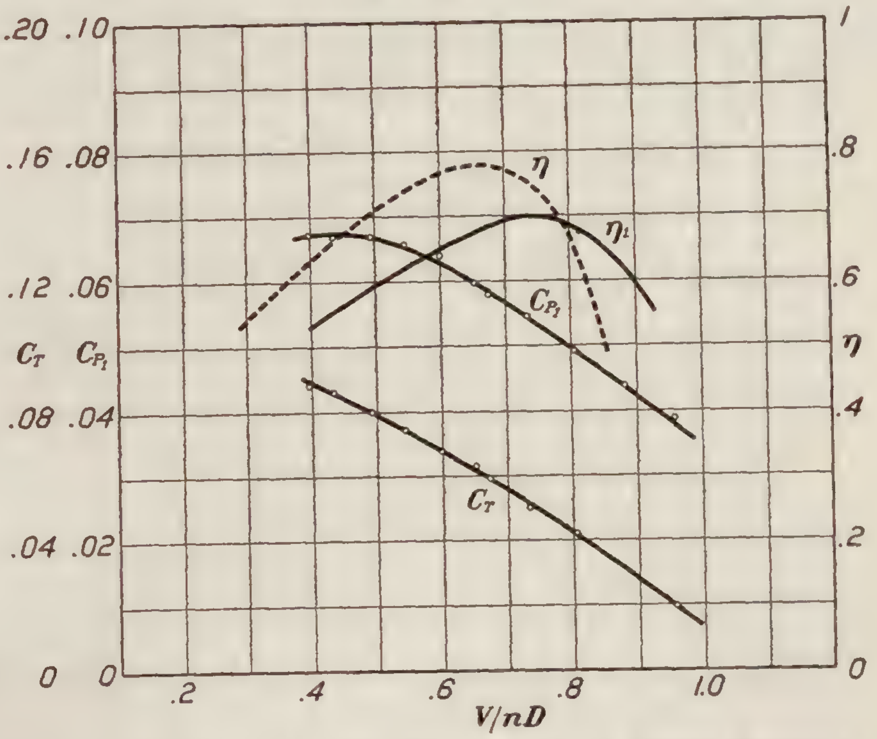


FIG. 21.—Propeller No. 1. Pitch ratio .7. Model B—fuselage clearance 4 inches

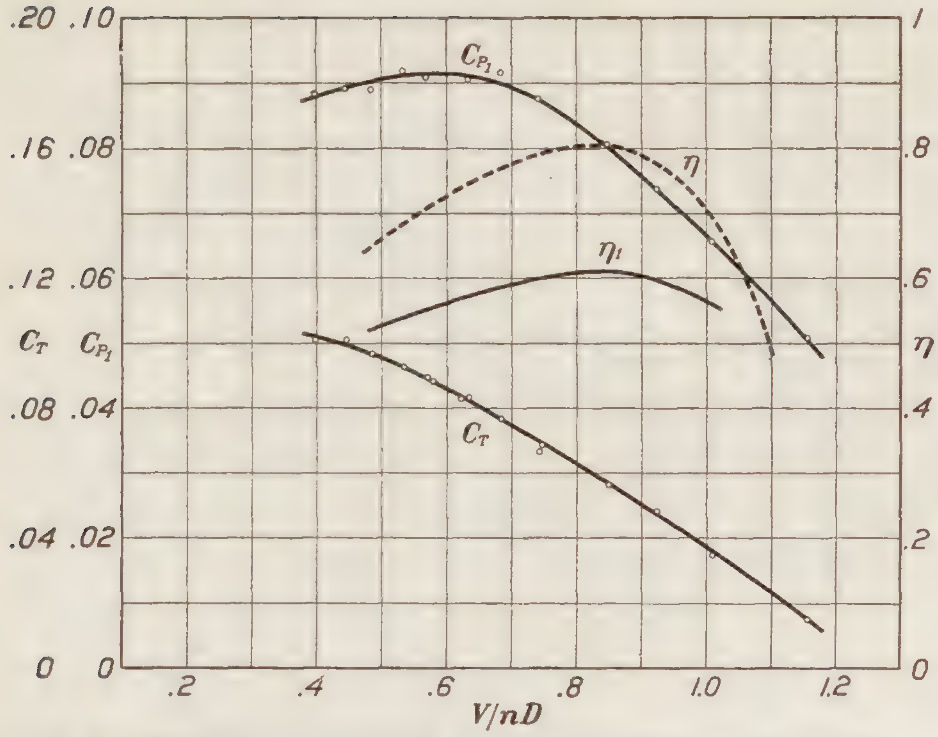


FIG. 22.—Propeller No. 2. Pitch ratio .9. Model B—fuselage clearance 0.375 inch

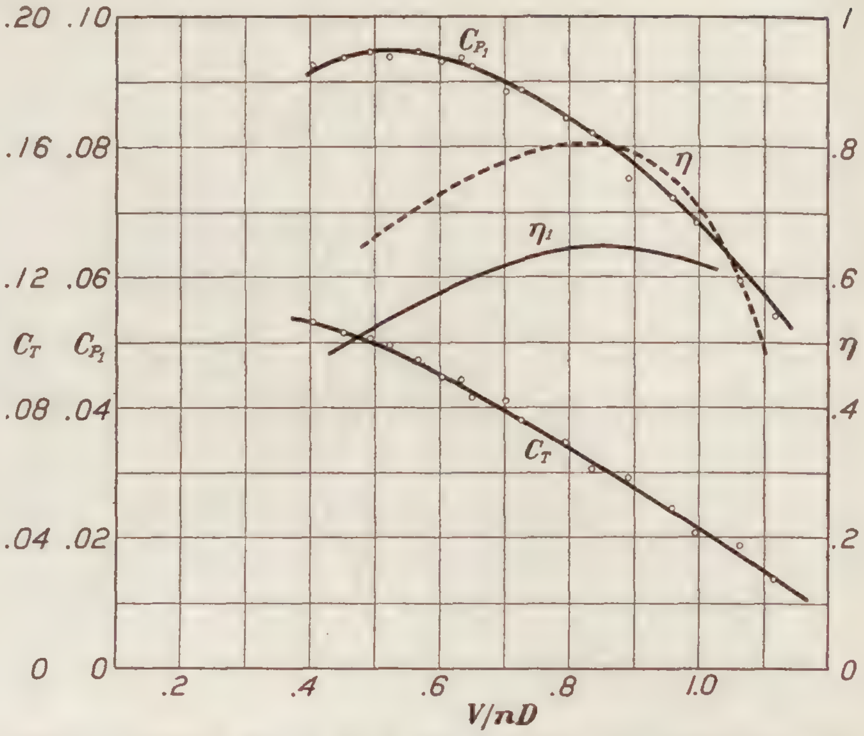


FIG. 23.—Propeller No. 2. Pitch ratio .9. Model B—fuselage clearance 2 inches

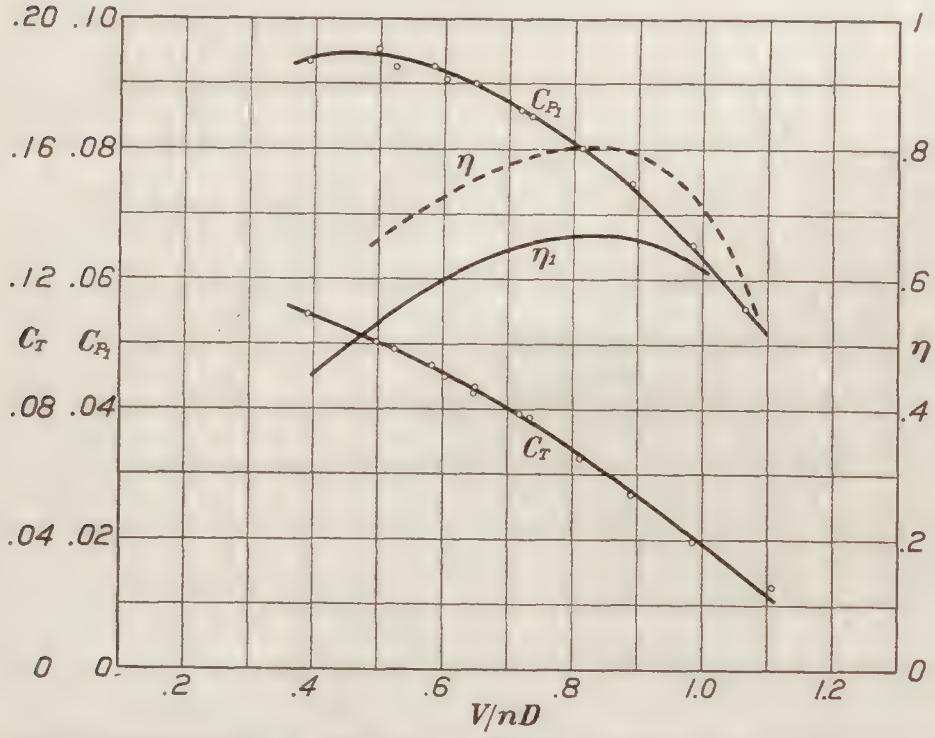


FIG. 24.—Propeller No. 2. Pitch ratio .9. Model B—fuselage clearance 4 inches

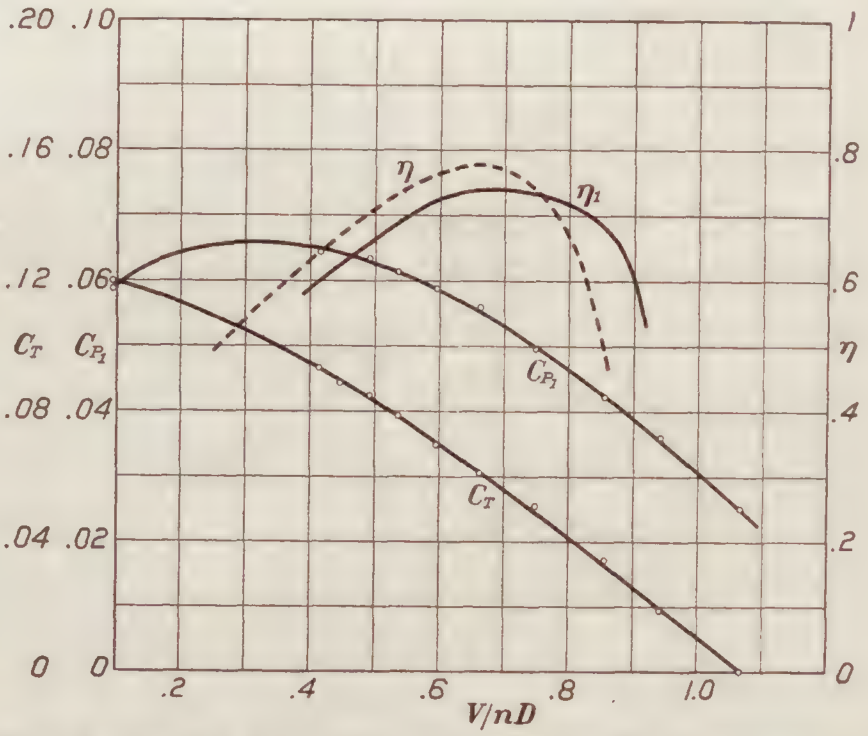


FIG. 25.—Propeller No. 1. Pitch ratio .7. Model C—DeHavilland. Clearance 0.375 inch. Radiator, wire gauze

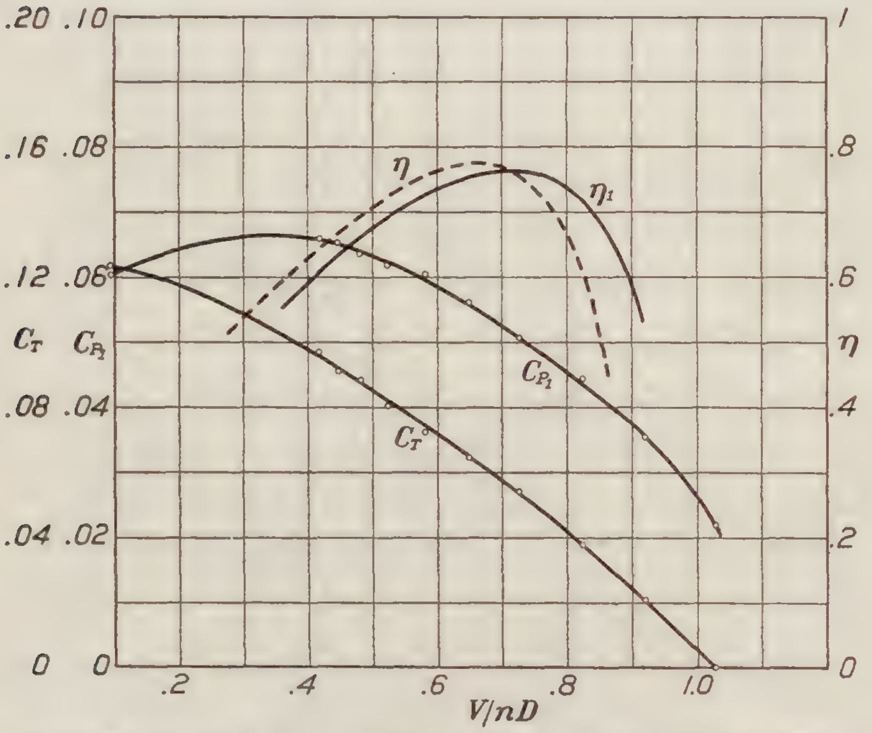


FIG. 26.—Propeller No. 1. Pitch ratio .7. Model C—DeHavilland. Clearance 4 inches. Radiator, wire gauze

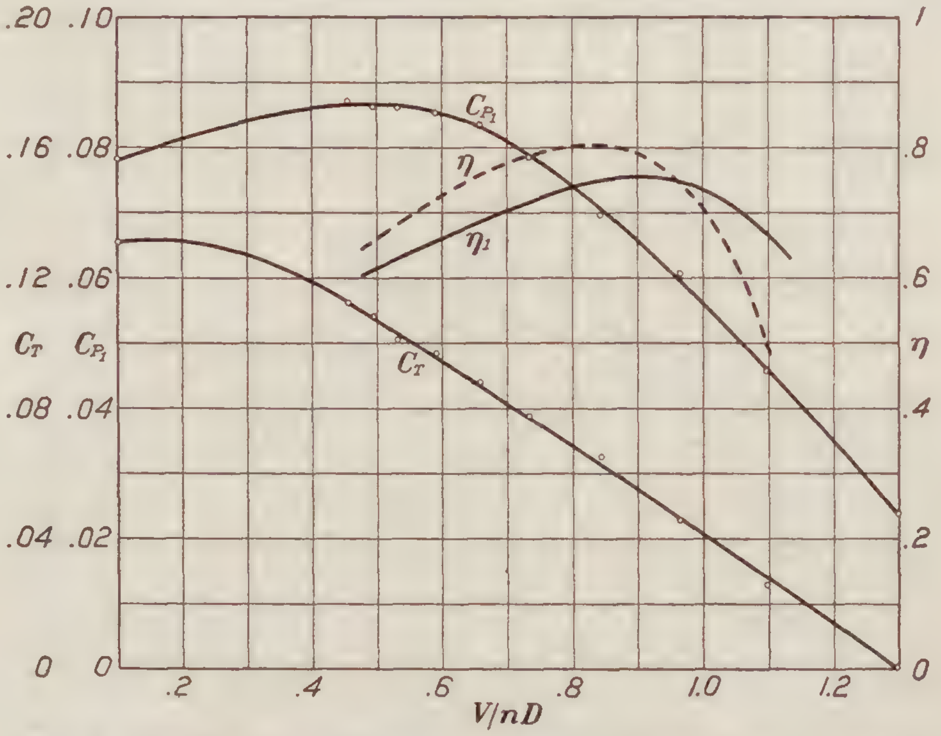


FIG. 27.—Propeller No. 2. Pitch ratio .9. Model C—DeHavilland. Clearanec 0.375 inch. Radiator, wire gauze

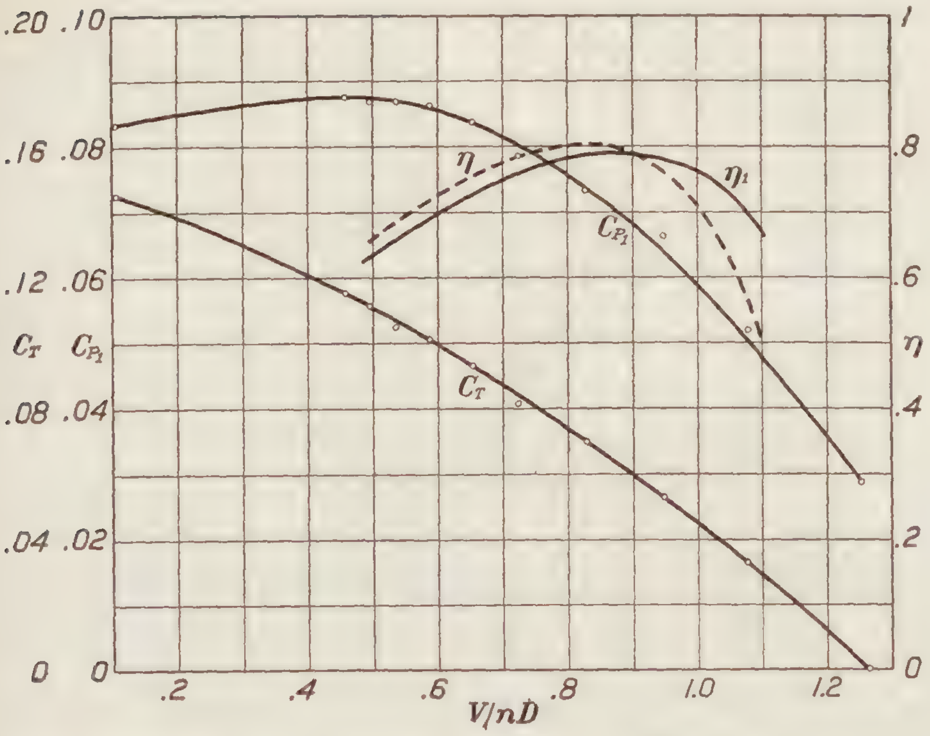


FIG. 28.—Propeller No. 2. Pitch ratio .9. Model C—DeHavilland. Clearance 4 inches. Radiator, wire gauze

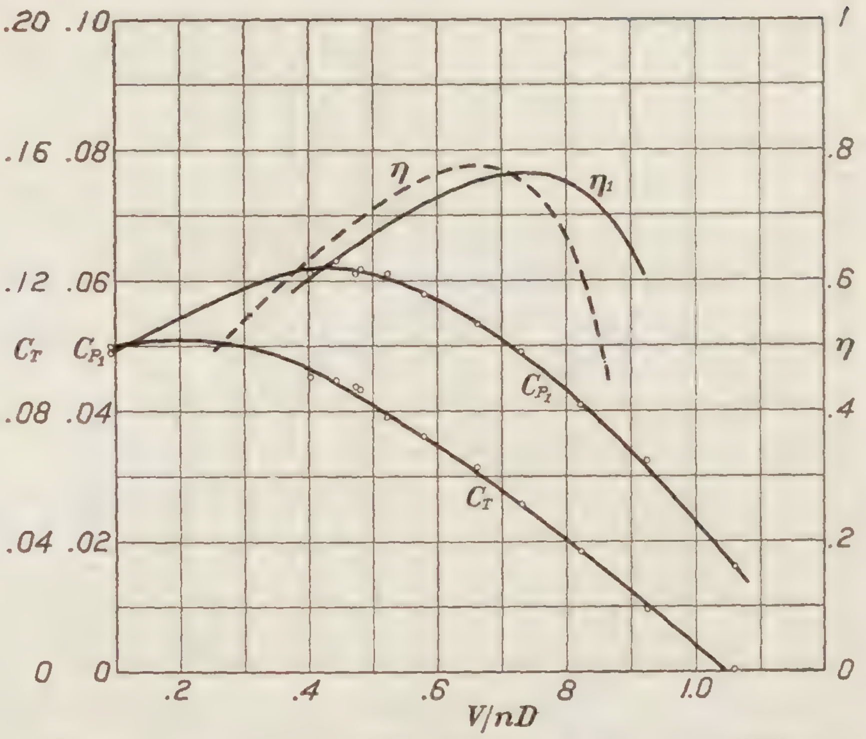


FIG. 29.—Propeller No. 1. Pitch ratio .7. Model C—DeHavilland. Clearance 0.375 inch. Radator, space open

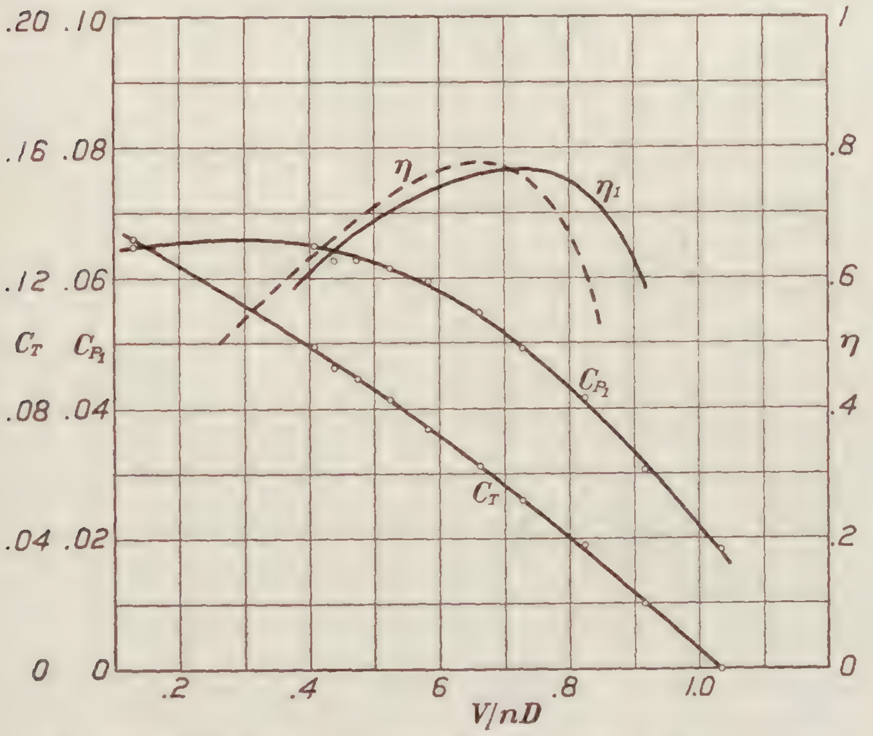


FIG. 30.—Propeller No. 1. Pitch ratio .7. Model C—DeHavilland. Clearance 4 inches. Radiator, space open

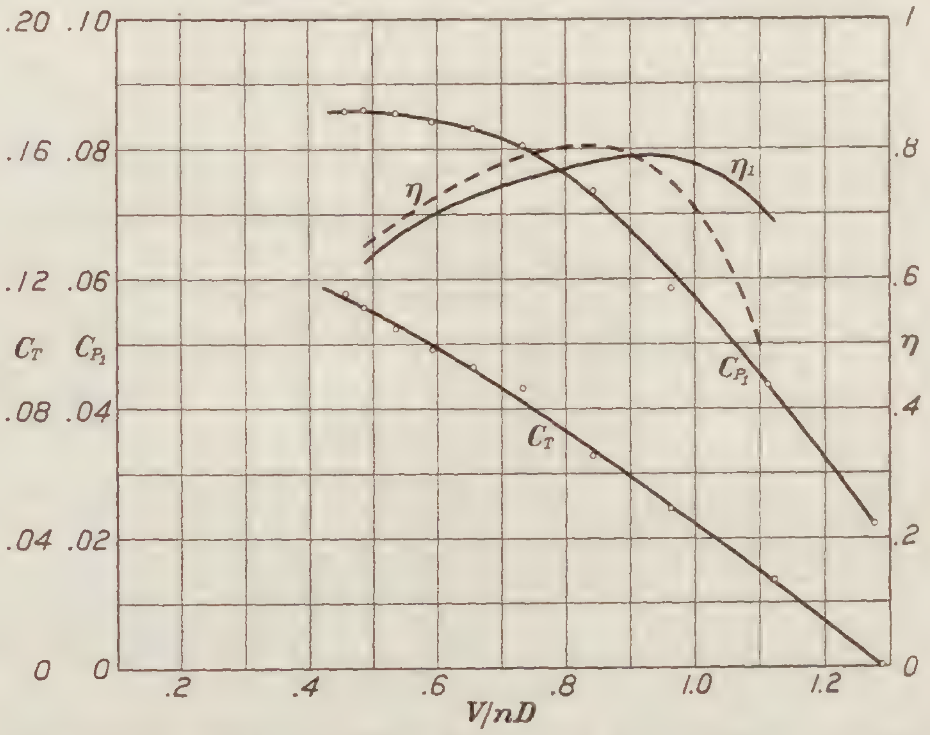


FIG. 31.—Propeller No. 2. Pitch ratio .9. Model C—DeHavilland. Clearance 0.375 inch. Radiator, space open

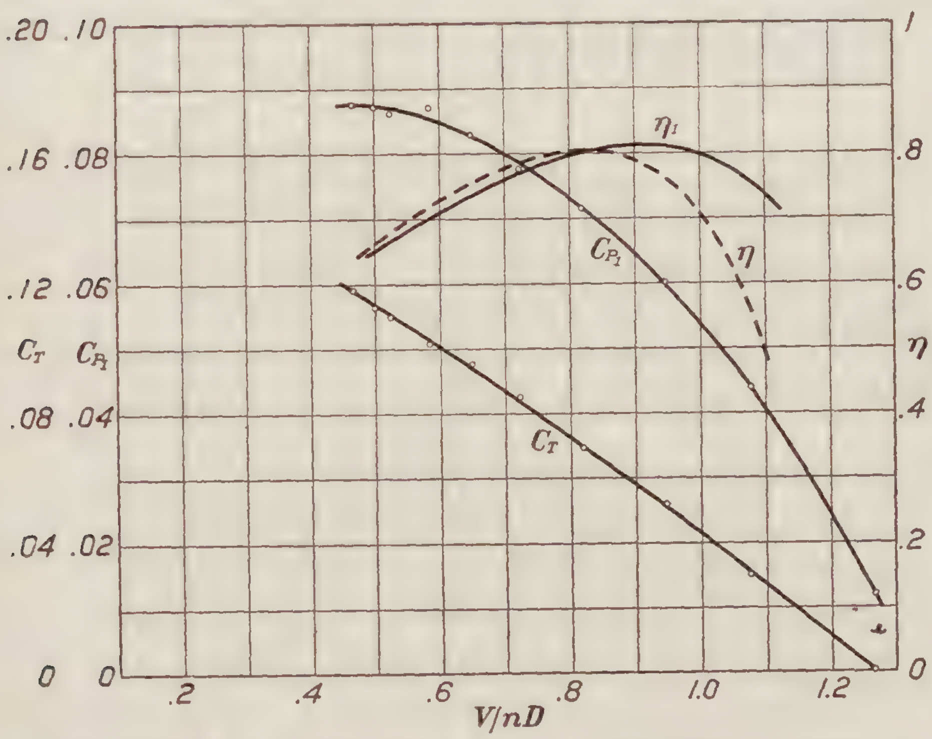


FIG. 32.—Propeller No. 2. Pitch ratio .9. Model C—DeHavilland. Clearance 4 inches. Radiator, space open

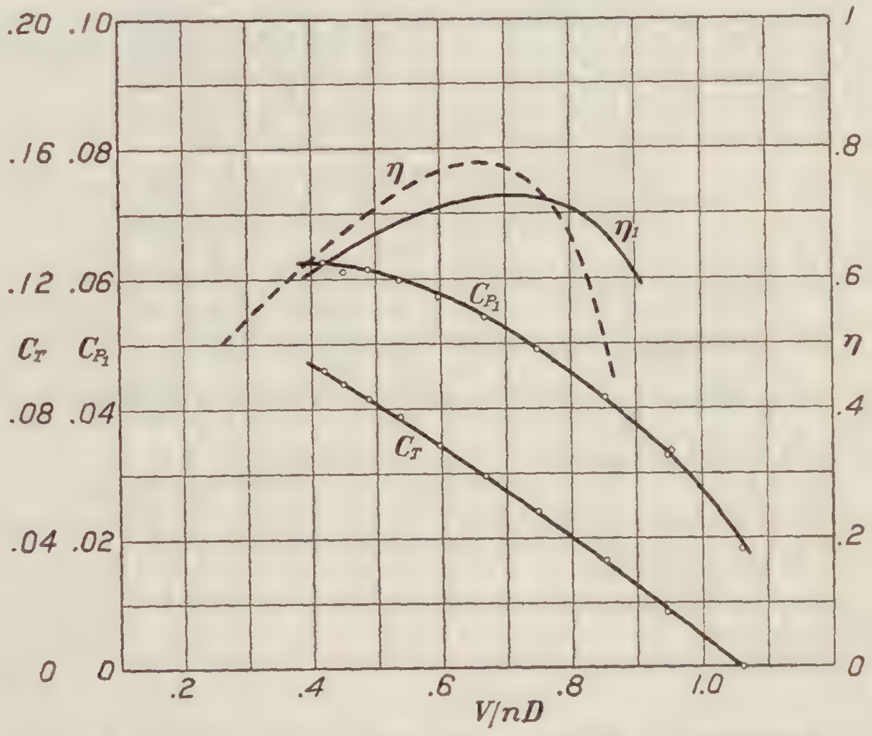


FIG. 33.—Propeller No. 1. Pitch ratio .7. Model C—DeHavilland. Clearance 0.375 inch. Radiator, closed

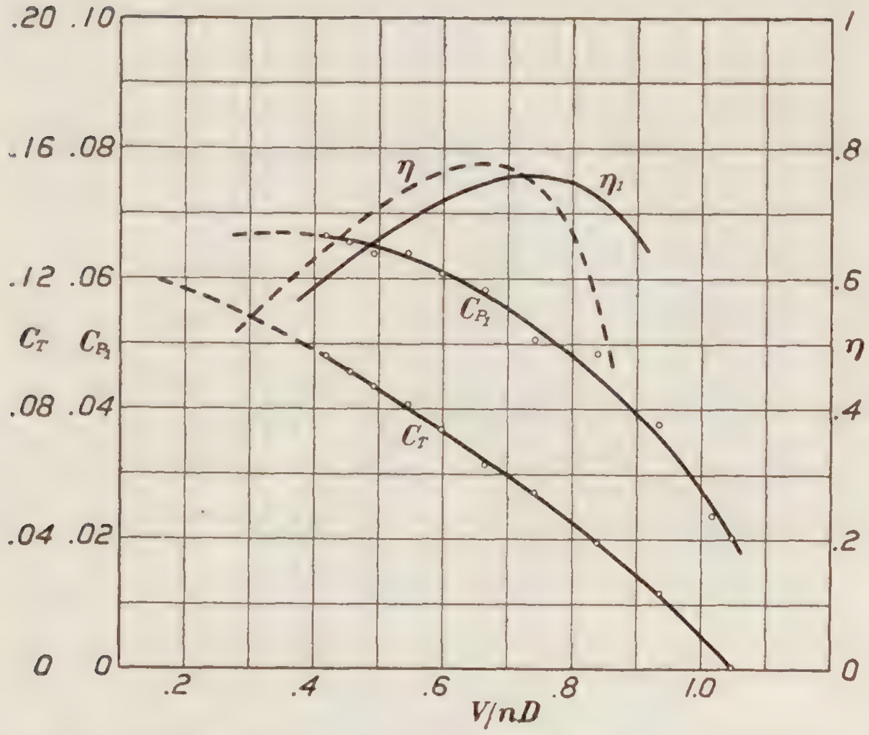


FIG. 34.—Propeller No. 1. Pitch ratio .7. Model C—DeHavilland. Clearance 4 inches. Radiator, closed

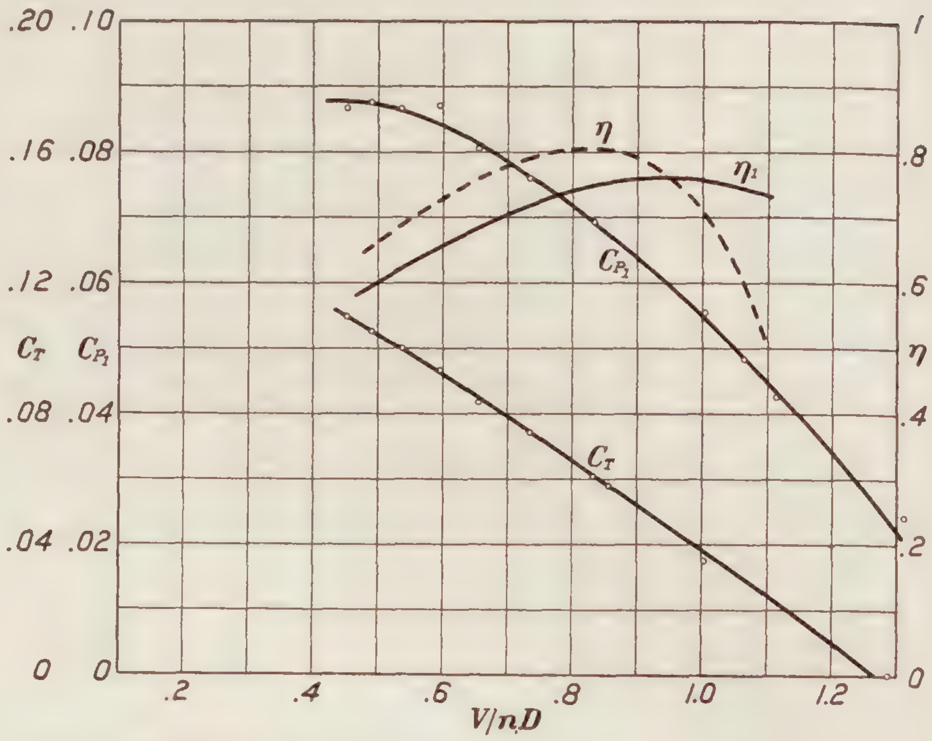


FIG. 35.—Propeller No. 2. Pitch ratio .9. Model C—DeHavilland. Clearance 0.375 inch. Radiator, closed

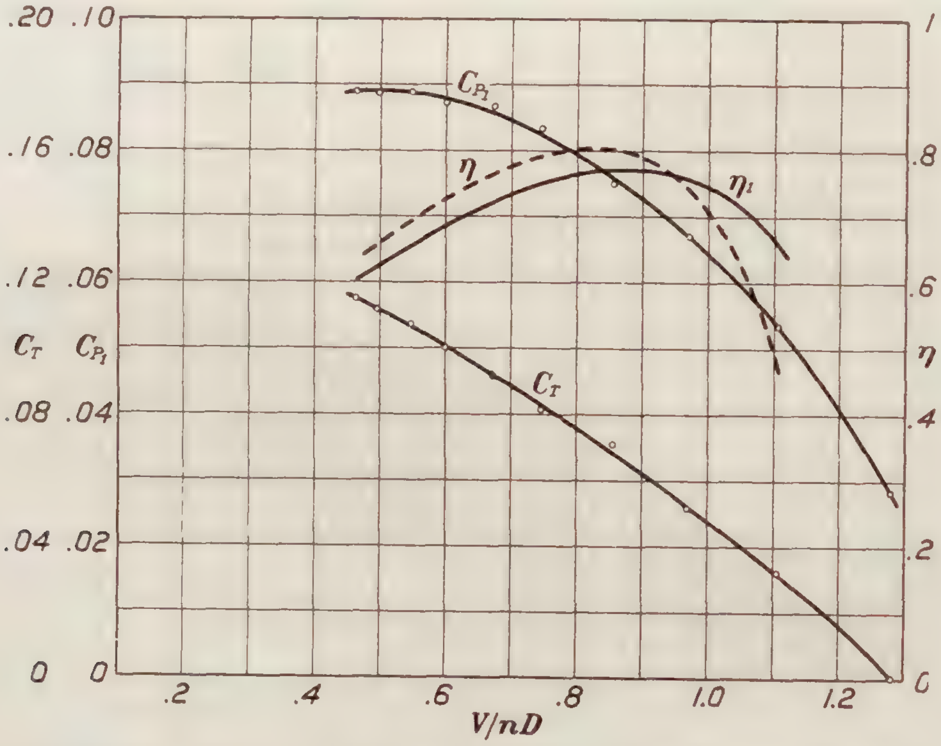


FIG. 36.—Propeller No. 2. Pitch ratio .9. Model C—DeHavilland. Clearance 4 inches. Radiator, closed

Other notation as per standard.

Graphical representations of these results are shown in the diagrams of Figures 10 to 36.

In these diagrams the individual values of the two coefficients are represented by the plotted points. A smooth curve as best indicating a continuous and consistent law is then drawn through and among these spots, and such curve is accepted as the best indication of the law relating the values of the coefficient to varying V/nD. The values of the efficiency η are then derived from the smooth curves of these coefficients and are plotted as shown in the various diagrams.

Tables I and II and Figures 10 and 11 give the results for the two propellers alone, and Tables III to XXVI and Figures 13 to 36 give those for the various combinations of propeller and model as stated. In each of the latter cases the efficiency curve for the propeller alone is also shown for comparison.

In Figure 12 are shown, for a single case, the curves for thrust and power coefficients with the resulting efficiency curves for the propeller alone and for the propeller with model. To avoid complication of diagrams, the coefficient curves for the propeller alone are omitted in Figures 13 to 36.

DISCUSSION OF RESULTS

In all cases, as shown on the various diagrams, the presence of an obstruction behind the propeller has the effect of moving to the right, on the axis of V/nD, the point for zero thrust. This is especially brought out in the diagram of Figure 12 where the coefficient curves for the propeller alone and for the propeller combined with model are shown together. Comparison with the other diagrams will show, in varying degrees, the same general condition.

This result is readily seen to follow as a natural consequence of the slowing down of the column of air actually operative on the propeller, as compared with the air passing freely at the side of the obstruction. For any given value of wind velocity as based on the latter, the air column acting on the propeller will be slowed down, the value of n for zero thrust will be decreased and the value of V/nD for zero thrust will be correspondingly increased.

From this shift of the point for zero thrust, it naturally results that the curve for thrust, or thrust coefficient, for the combined case, as compared with that for the propeller alone, starts farther to the right and near the start lies above that for the propeller alone. Hence for large values of V/nD (small values of the slip) the curve for propeller with model will lie above that for the propeller alone, as shown in Figures 12.

As the slip increases, however, and the value of V/nD becomes less, the two curves approach and meet and cross, thus bringing the values of the combination thrust coefficient for moderate and large values of the slip below those for the propeller alone. This condition, in general, is found to prevail over the normal working range of values of V/nD.

Similarly, for the torque coefficient, the values for large V/nD are greater than for the propeller alone, but the excess decreases with decreasing values of V/nD until the two sets of values become practically the same, and in many cases the curves cross and the values for the combination become less than those for the propeller alone.

It results that over the low value range of V/nD the values of the thrust coefficient for the combination are definitely less than for the propeller alone, while those for the power coefficient are nearly the same or slightly less. In all cases, however, and as illustrated in Figure 12, the decrease in the values of the thrust coefficient is greater than that for the power coefficient, and hence there results a loss in efficiency, as is shown in all cases.

On the other hand, however, and as must result from the forms of the coefficient curves, the values of the efficiency for large values of V/nD will be greater for the combination than for the propeller alone. Thus at the value of V/nD for zero thrust for the propeller alone, and hence for zero efficiency, the propeller combined with model will show a definite thrust and hence a definite (though low) efficiency. It thus results that the two efficiency curves must meet and cross, the combination values for moderate and low values of V/nD showing a loss as compared with the propeller alone, while over a range of relatively high V/nD (low slip) the combination values will be the larger.

It is well known that, due to limitations in diameter, air propellers must, in general, be used over a range of values of V/nD beginning with a large value somewhat less than that for maximum efficiency and extending over a small range in the direction of decreasing values. Inspection of Figures 13 to 36 will show that this range of values of V/nD carries the practical operation of the propeller over into that segment of the efficiency curve where the effect of an obstruction as represented by a thick wing, the nose of the fuselage, or other part of the airplane structure will be to decrease the propulsive efficiency as compared with that for the propeller alone at the same value of V/nD.

The amount of such loss in propulsive efficiency is seen to vary between wide limits according to the circumstances of the case. For model B, losses of the order of 15 and 20 points were found. For model A the values ranged somewhat smaller and for model C, as would be expected, still less.

A marked decrease in the loss is found to result from increased clearance between propeller and obstruction. This indicates very clearly that, in large degree, such loss in propulsive efficiency may be avoided by a suitable increase in this clearance, and, in general, it shows that with the tractor propeller the clearance between the propeller blades and the nearest parts of the airplane structure should be made as large as practicable.

So far as a comparison between the results for propellers 1 and 2 may serve to indicate, the loss in propulsive efficiency, other things the same, is the larger for No. 2 (the higher pitch ratio) than for No. 1.

The results of these observations indicate:

(1) The importance of taking some account, in problems of design, of this element of interaction between the propeller and the airplane.

(2) The desirability of avoiding such form and disposition of structure as will involve any extreme degree of interference as is shown by models A and B, or if such designs are imposed, then especial effort should be made to increase, to the maximum practicable limit, the clearance between the propeller and the nearer parts of the structure.

TABLE I

CHARACTERISTIC COEFFICIENTS FOR PROPELLER NO. 1

DIAMETER, 24 INCHES. NOMINAL PITCH RATIO, 0.70

$\frac{1}{2}\rho V^2$	V	N	T	Q	V/nD	C_T	C_{P_1}
1.744	38.70	1,274	0.180	0.175	0.9113	0.0107	0.0327
2.363	45.00	1,716	1.222	.432	.7868	.0400	.0445
2.338	45.34	1,755	1.237	.446	.7750	.0397	.0450
2.059	42.88	1,905	2.203	.608	.6752	.0610	.0529
2.558	47.56	2.278	3.601	.969	.6264	.0691	.0564
2.360	45.02	2,169	3.347	.866	.6227	.0688	.0559
2.349	45.47	2.205	3.370	.879	.6187	.0687	.0561
1.837	39.97	2,090	3.393	.874	.5737	.0760	.0590
2.383	45.29	2,379	4.437	1.104	.5711	.0759	.0593
2.424	45.72	2,561	5.550	1.318	.5356	.0821	.0613
2.495	46.39	2,737	6.724	1.517	.5085	.0871	.0617
2.257	44.50	2,719	6.715	1.504	.4910	.0897	.0631
2.505	46.50	3,027	8.874	1,917	.4608	.0940	.0638
2.817	49.35	3,320	11.050	2.302	.4459	.0975	.0638
2.174	43.30	3,238	11.150	2.230	.4011	.1032	.0648

TABLE II

CHARACTERISTIC COEFFICIENTS FOR PROPELLER NO. 2

DIAMETER, 24 INCHES. NOMINAL PITCH RATIO, 0.90

$\frac{1}{2}\rho V^2$	V	N	T	Q	V/nD	C_T	C_{P_1}
3.860	58.20	1,501	0.0882	0.187	1.163	0.0039	0.0257
1.912	40.95	1,068	.0617	.145	1.150	.0053	.0393
3.879	58.32	1,762	1.191	.529	.993	.0378	.0527
1.946	41.31	1,384	1.065	.395	.895	.0548	.0638
3.870	58.30	1,994	2.349	.829	.873	.0603	.0668
3.879	58.34	2,166	3.462	1.121	.808	.0728	.0741
1.962	41.53	1,630	2.213	.657	.764	.0786	.0768
2.570	47.28	1,939	3.312	.971	.731	.0861	.0793
2.008	41.85	1,864	3.305	.934	.674	.0935	.0830
2.606	47.65	2,153	4.508	1.267	.664	.0953	.0842
4.050	59.62	2,929	8.976	2.349	.611	.1034	.0851
2.613	47.77	2,326	5.562	1.510	.616	.1010	.0861
2.016	42.14	2,226	5.414	1.422	.568	.1083	.0893
4.077	59.82	3,178	11.334	2.871	.565	.1109	.0883
2.716	48.76	2,787	8.969	2.231	.525	.1138	.0889
2.763	49.17	3,010	11.092	2.622	.490	.1205	.0895
2.273	44.23	2,920	11.050	2.519	.454	.1252	.0897

TABLE III

PROPELLER NO. 1. PITCH RATIO, 0.7

MODEL A—WING

CLEARANCE, ⅜ INCH

$\frac{1}{2}\rho V^2$	V	N	T	R_a	R_o	A	$T-A$	Q	V/nD	C_T	C_{P_1}
1.885	40.80	1,279	0.648	0.877	0.603	0.274	0.374	----------	0.9570	0.0227	----------
2.391	46.10	1,516	1.131	1.213	.765	.448	.683	0.332	.9123	.0297	0.0554
2.988	50.29	1,723	1.676	1.570	.956	.614	1.062	.448	.8756	.0341	.0451
3.122	51.51	1,944	2.602	1.930	.999	.931	1.671	.644	.7949	.0423	.0512
3.040	50.73	1,949	2.690	1.850	.973	.877	1.813	.665	.7810	.0455	.0524
2.401	46.21	1,804	2.338	1.562	.768	.794	1.544	.559	.7684	.0475	.0540
3.005	49.51	2,109	4.201	2.240	.963	1.277	2.924	.961	.6797	.0562	.0580
2.415	46.38	2,242	4.629	2.120	.773	1.347	3.282	.948	.6207	.0655	.0594
3.194	52.05	2,625	6.704	2.920	1.022	1.898	4.806	1.389	.5949	.0666	.0604
3.490	54.83	2,966	8.877	3.609	1.117	2.492	6.385	1.763	.5546	.0703	.0610
3.536	55.19	3,238	10.800	4.209	1.132	3.077	7.723	2.110	.5114	.0714	.0613
2.499	47.13	2,897	8.848	3.158	.800	2.358	6.490	1.617	.4880	.0773	.0605
2.255	45.70	3,004	10.043	3.362	.772	2.640	7.403	1.761	.4462	.0817	.0610
2.036	42.53	3,528	14.544	4.508	.652	3.856	10.688	2.366	.3616	.0858	.0596

TABLE IV

CLEARANCE, 2 INCHES

2.999	50.34	1,599	1.180	1.410	0.960	0.450	0.730	0.334	0.9442	0.0271	0.0390
2.902	49.58	1,622	1.213	1.325	.929	.396	.817	.352	.9172	.0296	.0401
3.126	51.13	1,900	2 370	1.690	1 000	.690	1.680	.597	.8074	.0438	.0489
4.152	60.50	2.478	4.666	2.507	1.329	1.178	3.488	1.091	.7325	.0563	.0554
3.683	56.75	2,565	5 645	2.539	1.179	1.360	4.285	1.239	.6643	.0642	.0583
3.306	52.89	2,491	5.579	2.420	1.058	1.362	4.217	1.208	.6370	.0647	.0582
3.753	57.22	2,869	7.751	3.017	1.201	1.815	5.936	1.607	.5978	.0707	.0601
2.491	46.73	2,601	6.742	2.322	.797	1.525	5.217	1.337	.5390	.0761	.0612
2.844	49.39	3,018	10.043	3.213	.910	2.303	7.740	1.837	.4909	.0820	.0611
3.238	52.38	3,378	13.430	4.140	1.036	3.104	10.326	2.340	.4652	.0863	.0614
2.530	47 11	3,140	11.160	3.248	.810	2.438	8.722	1.938	.4501	.0873	.0609
1.968	41.50	2,821	8.966	2.620	.630	1.990	6.976	1.541	.4413	.0863	.0599
1.964	41.47	3,079	11.100	3.013	.628	2.385	8.715	1.813	.4041	.0906	.0592
1.972	41.54	3,406	----------	----------	----------	----------	----------	2.192	.3659	----------	.0584

TABLE V

CLEARANCE, 4 INCHES

3.087	51.15	1,699	1.210	1.230	0.988	0.242	0.968	0.405	0.9032	0.0336	0.0420
4.508	63.05	2,158	2.192	1.870	1.442	.428	1.764	.649	.8764	.0376	.0434
3.554	55.84	2,024	2.218	1.592	1.137	.455	1.763	.631	.8277	.0425	.0478
3.100	51.28	1,950	2.360	1.450	.992	.458	1.902	----------	.7890	.0478	----------
2.838	48.65	1,853	----------	----------	----------	----------	----------	.573	.7878	----------	.0492
4.662	64.20	2,585	4.428	2.374	1.491	.883	3.545	1.122	.7452	.0528	.0525
4.314	61.57	2,544	4.598	2.295	1.380	.915	3.683	1.108	.7260	.0563	.0532
1.902	41.28	1,744	2.192	1.051	.609	.442	1.750	.529	.7100	.0581	.0553
3.349	53.28	2,370	4.565	1.980	1.071	.909	3.656	1.053	.6745	.0621	.0562
3.080	52.03	2,333	----------	----------	----------	----------	----------	.984	.6690	----------	.0561
4.688	64.36	2,888	----------	----------	----------	----------	----------	1.496	.6684	----------	.0560
2.932	49.51	2,253	4.366	1.831	.939	.892	3.474	----------	.6592	.0642	----------
4.288	61.43	2,851	6.812	2.632	1.371	1.261	5.551	1.486	.6465	.0676	.0569
4.716	64.57	3,174	8.876	3.162	1.509	1.653	7.223	1.884	.6102	.0713	.0584
1.936	41.65	2,142	4.157	1.411	.620	.786	3.371	.857	.5833	.0763	.0592
3.143	51.68	2,674	6.770	2.270	1.006	1.264	5.506	1.407	.5797	.0736	.0591
3.960	59.03	3,088	8.823	2.923	1.267	1.656	7.167	1.833	.5735	.0744	.0598
3.298	52.88	2,989	8.980	2.780	1.055	1.725	7.255	1.817	.5307	.0774	.0609
1.993	42.25	2,562	6.726	1.852	.638	1.214	5.512	1.264	.4948	.0846	.0610
2.578	47.38	3,160	11.090	2.757	.825	1.932	9.158	2.004	.4498	.0898	.0618
2.003	42.31	2,870	8.958	2.260	.641	1.619	7.339	1.594	.4423	.0896	.0608
1.986	42.13	3,144	10.990	3.197	.657	1.983	9.007	1.884	.4060	.0934	.0614
2.053	42.83	3,490	14.680	2.621	.638	2.540	12.140	2.335	.3681	.0987	.0605

V=Velocity f. p. s.
N=R. P. M.
n=r. p. s.
T=Actual thrust lb.
R_a=Resistance of model with propeller in action, lb.
R_o=Resistance of model without propeller at same speed as for R_a, lb.
A=Augment of resistance=R_a-R_o.
Q=Torque, ft. lb.
D=Diameter of propeller, ft.
C_T=Thrust coef.=$(T-A)\div\rho n^2D^4$
C_{P_1}=Power coef.=$P\div\rho n^3D^5$
P=Power=$2\pi nQ$ ft. lb. sec.

TABLE VI

PROPELLER NO. 2. PITCH RATIO, 0.9

MODEL A—WING

CLEARANCE, ⅜ INCH

$\frac{1}{2}\rho V^2$	V	N	T	R_a	R_o	A	$T-A$	Q	V/nD	C_T	C_{P_1}
1.904	40.65	1,098	0.701	0.886	0.609	0.277	0.424	0.257	1.110	0.0343	0.0653
4.933	65.59	1,850	2.263	2.573	1.579	.994	1.269		1.064	.0364	
2.349	45.55	1,297						.357	1.054		.0663
2.855	48.45	1,447	1.610	1.500	.914	.586	1.024		1.004	.0452	
3.578	56.08	1,720	2.243	1.886	1.145	.741	1.502	.683	.978	.0502	.0717
5.085	66.64	2,213	4.382	3.153	1.627	1.526	2.856		.903	.0572	
2.622	47.16	1,634	2.429	1.514	.839	.675	1.754	.687	.866	.0627	.0772
4,483	62.20	2,331	5.615	3.182	1.435	1.747	3.868	1.438	.802	.0694	.0810
5.117	67.00	2,800	8.910	4.403	1.637	2.766	6.144		.718	.0774	
1.885	40.66	1,750	3.416	1.535	.603	.932	2.481	.821	.697	.0800	.0831
3.896	57.95	2,686	8.852	3.700	1.247	2.453	6.399	1.951	.647	.0860	.0823
2.472	45.60	2,178	5.760	2.318	.786	1.532	4.228	1.316	.628	.0849	.0830
3.878	57.82	2,929	11.040	4.233	1.241	2.992	8.048	2.317	.592	.0909	.0823
1.928	41.21	2,122	5.599	2.060	.617	1.443	4.156		.582	.0912	
1.975	41.71	2,275	6.672	2.306	.632	1.674	4.998	1.361	.550	.0957	.0819
3.136	51.44	2,921	11.444	3.980	1.003	2.977	8.467	2.343	.528	.0944	.0818
1.985	41.82	2,806	11.032	3.269	.635	2.634	8.398	2.019	.447	.1057	.0798
1.995	41.93	3,166	14.404	3.942	.638	3.304	11.100	2.556	.397	.1096	.0793

TABLE VII

CLEARANCE 2 INCHES

4.222	60.73	1,793	2.293	2.020	1.351	0.669	1.624	0.712	1.0163	0.0496	0.0683
3.051	51.51	1,659	2.183	1.573	.976	.597	1.586	.657	.9324	.0563	.0733
4.234	60.84	2,187	4.472	2.583	1.354	1.229	3.243	1.221	.8345	.0667	.0789
1.929	40.67	1,537						.620	.7938		.0799
3.018	50.26	1,931	3.969	1.950	.966	.984	2.985		.7810	.0754	
4.305	61.37	2,498	6.660	2.997	1.377	1.620	5.040	1.654	.7370	.0795	.0820
3.005	50.15	2,237	5.954	2.360	.961	1.399	4.555	1.425	.6726	.0857	.0842
4.343	61.67	2,757	8.940	3.480	1.390	2.090	6.850	2.057	.6710	.0887	.0837
4.370	61.86	3,006	11.040	3.983	1.398	2.585	8.455	2.451	.6174	.0922	.0840
3.139	52.33	2,683	8.970	3.017	1.004	2.013	6.957	1.951	.5851	.0948	.0835
3.152	51.31	2,675	9.416	3.210	1.009	2.201	7.215	2.040	.5755	.0948	.0842
1.983	41.32	2,260	6.672	2.118	.634	1.484	5.188	1.393	.5485	.0984	.0830
3.173	52.61	2,907	11.100	3.502	1.015	2.487	8.613	2.276	.5430	.1000	.0830
3.173	51.49	2,946	11.690	3.680	1.015	2.665	9.025	2.474	.5243	.0977	.0842
2.043	41.93	2,560	8.866	2.626	.654	1.972	6.894	1.773	.4914	.1017	.0822
2.064	42.15	2,791	11.070	3.019	.660	2.359	8.711	2.061	.4531	.1084	.0805
2.091	42.48	3,144	14.390	3.743	.669	3.074	11.316	2.591	.4053	.1112	.0799

TABLE VIII

CLEARANCE, 4 INCHES

1.857	40.61	1,277	1.178	0.808	0.594	0.214	0.964	0.354	0.9540	0.0591	0.0681
3.200	53.03	1,724	2.304	1.530	1.024	.506	1.798	.683	.9228	.0599	.0714
4.947	66.36	2,313	4.530	2.534	1.583	.951	3.579	1.275	.8608	.0670	.0750
3.177	51.80	1,995	3.969	1.770	1.017	.753	3.216	1.056	.7790	.0768	.0792
4.932	66.29	2,608	6.660	2.869	1.578	1.291	5.369	1.731	.7625	.0793	.0801
3.228	53.33	2,120	4.448	1.888	1.038	.850	3.598	1.159	.7547	.0793	.0803
3.143	51.32	2,086	4.609	1.870	1.007	.863	3.746	1.186	.7380	.0811	.0807
3.207	52.59	2,368	6.318	1.748	.642	1.106	5.212	1.519	.6667	.0898	.0827
3.137	51.62	2,418	7.123	2.320	1.015	1.305	5.818	1.678	.6404	.0940	.0852
3.825	58.23	2,996	10.910	3.263	1.224	2.039	8.871	2.427	.5831	.0986	.0847
3.332	52.95	2,986	11.732	3.170	1.066	2.104	9.628	2.546	.5320	.1022	.0849
2.270	44.57	2,615	8.876	2.356	.726	1.630	7.246	1.851	.5113	.1043	.0837
2.272	44.62	2,867	11.065	2.726	.727	1.999	9.066	2.188	.4669	.1087	.0824
2.007	42.41	3,042	12.745	2.923	.642	2.281	10.464	2.420	.4182	.1130	.0824

V=Velocity f. p. s.
N=R. P. M.
n=r. p. s.
T=Actual thrust, lb.
R_a=Resistance of model with propeller in action, lb.
R_o=Resistance of model without propeller at same speed as for R_a, lb.

A=Augment of resistance=R_a-R_o
Q=Torque, ft. lb.
D=Diameter of propeller, ft.
C_T=Thrust Coef.=$(T-A)\div\rho n^2D^4$.
C_{P_1}=Power Coef.=$P\div\rho n^3D^5$.
P=Power=$2\pi nQ$ ft. lb. sec.

TABLE IX

PROPELLER No. 1 PITCH RATIO, 0.7

MODEL B—FUSELAGE

CLEARANCE ⅜ INCH

$\frac{1}{2}\rho V^2$	V	N	T	R_a	R_o	A	$T-A$	Q	V/nD	C_T	C_{P_1}
4.730	64.60	1,951	1.298	5.076	4.170	0.906	0.392	0.441	0.9932	0.0102	0.0361
3.068	51.70	1,604	1.028	3.286	2.651	.635	.393	.338	.9678	.0150	.0405
1.905	41.20	1,299	.666	1.991	1.675	.316	.350	.224	.9515	.0208	.0418
3.060	51.65	1,882	2.238	3.635	2.648	.987	1.251	.589	.8234	.0347	.0513
1.875	40.85	1,738	2.338	2.469	1.642	.827	1.511	.576	.7052	.0501	.0600
4.235	61.30	2,780	6.620	6.065	3.740	2.325	4.295		.6616	.0555	
4.235	61.45	3,085	8.820	6.760	3.755	3.005	5.815	1.987	.5975	.0613	.0658
3.170	52.70	2,650	6.640	5.013	2.756	2.257	4.383	1.500	.5966	.0615	.0662
1.913	41.40	2,193	4.560	3.158	1.695	1.463	3.097	1.015	.5663	.0649	.0670
4.225	61.35	3,330	11.140	7.251	3.748	3.503	7.637	2.356	.5528	.0691	.0669
3.175	52.70	2,964	8.980	5.617	2.756	2.866	6.119	1.921	.5334	.0686	.0676
3.196	52.95	3,213	11.080	6.236	2.785	3.451	7.629	2.285	.4944	.0729	.0686
1.997	42.27	2,855	8.950	4.505	1.772	2.733	6.217	1.726	.4441	.0768	.0670
2.010	42.43	3,122	11.140	5.135	1.790	3.345	7.795	2.067	.4077	.0806	.0676
2.040	42.77	3,460	14.310	6.026	1.820	4.206	10.104	2.511	.3709	.0852	.0665

TABLE X

CLEARANCE, 2 INCHES

4.348	61.25	1,889	1.172	4.305	3.632	0.673	0.499	0.418	0.9728	0.0136	0.0357
3.357	52.71	1,793	1.638	3.762	2.750	.626	1.012	.478	.8845	.0295	.0438
2.815	49.18	1,875	2.290	3.154	2.409	.745	1.545	.587	.7868	.0425	.0507
4.650	63.40	2,510	4.565	5.490	4.010	1.480	3.085	1.120	.7578	.0476	.0543
4.640	63.35	2,834	6.650	6.006	4.001	2.005	4.645	1.585	.6706	.0563	.0604
2.240	43.55	1,988	3.510	3.878	1.885	1.993	1.517	.808	.6572	.0607	.0612
2.937	50.25	2,595	6.690	4.300	2.512	1.783	4.902	1.435	.3809	.0704	.0657
3.073	49.63	2,621	7.362	4.656	2.610	2.044	5.318		.5681	.0698	
1.582	36.80	2,258	5.635	2.794	1.290	1.504	4.131	1.124	.4890	.0781	.0667
2.960	50.30	3,178	11.210	5.456	2.535	2.921	8.289	2.194	.4768	.0796	.0662
1.629	37.34	2,725	8.945	3.682	1.335	2.347	6.598	1.645	.4111	.0856	.0671
1.637	37.44	3,002	11.190	4.285	1.344	2.941	8.249	2.017	.3742	.0882	.0678
1.645	37.33	3,351	14.380	5.130	1.352	3.778	10.602	2.462	.3361	.0912	.0664

TABLE XI

CLEARANCE, 4 INCHES

4.360	61.35	1,918	1.142	4.161	3.747	0.414	0.728	0.464	0.9598	0.0195	0.0385
1.802	39.52	1,345						.257	.8816		.0435
3.295	53.25	1,982	2.365	3.496	2.810	.686	1.679	.633	.8060	.0414	.0491
4.390	61.65	2,514	4.475	5.031	3.783	1.248	3.227	1.120	.7358	.0498	.0543
3.286	53.15	2,359	4.575	3.994	2.805	1.189	3.386	1.058	.6760	.0589	.0577
3.699	55.55	2,553	5.459	4.163	3.040	1.123	4.336	1.315	.6528	.0625	.0595
3.186	51.31	2,616	6.175	4.036	2.615	1.421	4.754	1.436	.6002	.0672	.0638
2.600	46.88	2,576	6.660	3.710	2.175	1.535	5.125	1.455	.5464	.0736	.0656
2.638	47.33	2,882	8.910	4.197	2.205	1.992	6.918	1.849	.4927	.0796	.0669
1.932	41.04	2,833	8.855	3.501	1.662	1.839	7.016	1.740	.4346	.0858	.0668
1.983	41.60	3,132	11.170	4.098	1.712	2.386	8.784	2.132	.3985	.0879	.0671

V=Velocity f. p. s.
N=R. P. M.
n=r. p. s.
T=Actual thrust, lb.
R_a=Resistance of model with propeller in action, lb.
R_o=Resistance of model without propeller at same speed as for R_a, lb.

A=Augment of resistance=R_a-R_o.
Q=Torque, ft. lb.
D=Diameter of propeller, ft.
C_T=Thrust coef.=$(T-A)\div\rho n^2D^4$.
C_{P_1}=Power coef.=$P\div\rho n^3D^5$.
P=Power=$2\pi nQ$ ft. lb. sec.

TABLE XII

PROPELLER NO. 2. PITCH RATIO, 0.9

MODEL B—FUSELAGE

CLEARANCE, ⅜ INCH

$\frac{1}{2}\rho V^2$	V	N	T	R_a	R_o	A	$T-A$	Q	V/nD	C_T	C_{P_1}
4. 401	62. 15	1, 613	1. 261	4. 711	3. 867	0. 844	0. 417	0. 427	1. 1560	0. 0158	0. 0509
4. 293	61. 45	1, 826	2. 378	4. 932	3. 755	1. 177	1. 201	. 704	1. 0098	. 0356	. 0656
1. 643	38. 36	1, 244	1. 232	1. 907	1. 425	. 482	. 750	. 360	. 9250	. 0488	. 0737
4. 315	61. 70	2, 177	4. 525	5. 440	3. 629	1. 811	2. 714	1. 221	. 8503	. 0568	. 0804
4. 448	62. 70	2, 519	6. 875	6. 378	3. 919	2. 459	4. 416		. 7468	. 0692	
2. 821	48. 56	1, 963	4. 212	3. 827	2. 357	1. 470	2. 742	1. 139	. 7421	. 0669	. 0873
4. 443	62. 70	2, 745	8. 790	6. 864	3. 919	2. 945	5. 845	2. 202	. 6853	. 0772	. 0914
2. 792	50. 11	2, 371	6. 715	4. 554	2. 494	2. 060	4. 655	1. 597	. 6341	. 0838	. 0903
4. 428	62. 70	3, 022	11. 230	7. 509	3. 919	3. 590	7. 640		. 6225	. 0832	
2. 950	51. 53	2, 667	8. 875	5. 308	2. 645	2. 663	6. 212		. 5800	. 0886	
3. 015	50. 25	2, 643	9. 482	5. 350	2. 535	2. 815	6. 667	2. 141	. 5704	. 0899	. 0908
2. 405	46. 07	2, 591	8. 922	4. 663	2. 021	2. 642	6. 280	1. 967	. 5340	. 0931	. 0916
1. 923	41. 31	2, 550	8. 905	4. 281	1. 687	2. 594	6. 311	1. 843	. 4860	. 0969	. 0889
1. 939	41. 52	2, 794	11. 075	4. 882	1. 706	3. 176	7. 899	2. 208	. 4459	. 1013	. 0889
1. 975	41. 90	3, 154	14. 410	5. 876	1. 740	4. 136	10. 274	2. 788	. 3986	. 1013	. 0881

TABLE XIII

CLEARANCE, 2 INCHES

3. 031	50. 64	1, 353	0. 910	2. 929	2. 549	0. 380	0. 530	0. 334	1. 1175	0. 0273	0. 0540
2. 795	49. 10	1, 384	1. 160	1. 766	1. 350	. 416	. 744	. 373	1. 0644	. 0377	. 0594
4. 163	60. 10	1, 808	2. 300	4. 494	3. 590	. 904	1. 396	. 727	. 9973	. 0417	. 0682
1. 893	41. 10	1, 285	1. 210	2. 073	1. 668	. 405	. 805	. 378	. 9597	. 0490	. 0722
2. 720	48. 45	1, 631	2. 310	3. 054	2. 340	. 714	1. 596	. 655	. 8912	. 0582	. 0751
4. 200	60. 45	2, 170	4. 510	5. 203	3. 630	1. 573	2. 937	1. 253	. 8358	. 0611	. 0819
1. 913	41. 35	1, 561	2. 325	2. 326	1. 690	. 636	1. 679	. 650	. 7947	. 0693	. 0843
3. 492	54. 72	2, 259	5. 640	4. 552	2. 936	1. 616	4. 024	1. 491	. 7268	. 0761	. 0886
1. 925	41. 50	1, 776	3. 420	2. 559	1. 708	. 851	2. 569	. 880	. 7010	. 0820	. 0883
3. 082	51. 17	2, 361	6. 685	4. 439	2. 590	1. 849	4. 836	1. 711	. 6502	. 0829	. 0922
2. 800	49. 17	2, 332	6. 670	4. 135	2. 407	1. 728	4. 942	1. 663	. 6326	. 0883	. 0934
3. 082	51. 17	2, 551	8. 287	4. 815	2. 591	2. 224	6. 063	2. 017	. 6018	. 0891	. 0931
2. 830	49. 46	2, 613	8. 935	4. 730	2. 432	2. 298	6. 637	2. 107	. 5679	. 0945	. 0943
2. 845	49. 60	2, 850	11. 100	5. 296	2. 450	2. 846	8. 254	2. 480	. 5221	. 0992	. 0937
2. 005	42. 40	2, 580	8. 835	3. 938	1. 786	2. 152	6. 683	1. 983	. 4930	. 1013	. 0944
2. 035	42. 75	2, 841	11. 040	4. 652	1. 819	2. 833	8. 207	2. 378	. 4514	. 1028	. 0936
2. 025	42. 65	3, 158	14. 090	5. 419	1. 807	3. 612	10. 478	2. 902	. 4052	. 1062	. 0925

TABLE XIV

CLEARANCE, 4 INCHES

4. 080	59. 10	1, 601	1. 129	3. 893	3. 447	0. 446	0. 683		1. 1080	0. 0257	
2. 983	50. 35	1, 428						0. 380	1. 0580		0. 0556
1. 422	35. 15	1, 071	. 746	1. 431	1. 148	. 283	. 463	. 244	. 9846	. 0395	. 0653
2. 232	43. 03	1, 450	1. 746	2. 408	1. 877	. 531	1. 215	. 336	. 8904	. 0539	. 0748
4. 067	59. 15	2, 189	4. 470	4. 705	3. 452	1. 253	3. 217	1. 262	. 8108	. 0650	. 0801
3. 003	50. 60	2, 067	4. 600	3. 689	2. 547	1. 142	3. 458	1. 205	. 7344	. 0776	. 0850
4. 164	59. 85	2, 496	6. 725	5. 219	3. 560	1. 659	5. 066	1. 763	. 7192	. 0787	. 0860
3. 095	51. 33	2, 368	6. 650	4. 192	2. 616	1. 576	5. 074	1. 678	. 6504	. 0867	. 0901
4. 192	60. 05	2, 772	8. 910	5. 761	3. 585	2. 176	6. 734	2. 274	. 6499	. 0848	. 0900
4. 233	60. 35	3, 010	11. 090	6. 272	3. 615	2. 657	8. 433	2. 705	. 6015	. 0901	. 0908
3. 095	51. 35	2, 645	8 875	4. 668	2. 618	2. 050	6. 825	2. 153	. 5825	. 0935	. 0927
1. 816	39. 83	2, 273	6. 700	3. 082	1. 555	. 527	5. 173	1. 551	. 5257	. 0984	. 0927
2. 107	42. 98	2, 585	8. 935	3. 730	1. 839	1. 891	7. 044	2. 052	. 4988	. 1040	. 0952
1. 530	36. 10	2, 767	11. 270	3. 792	1. 230	2. 562	8. 708	2. 373	. 3914	. 1090	. 0933

V=Velocity f. p.s.
N=R. P. M.
n=r. p. s.
T=Actual thrust, lb.
R_a=Resistance of model with propeller in action, lb.
R_o=Resistance of model without propeller at same speed as for R_a, lb.

A=Augment of resistance=$R_a—R_o$.
Q=Torque, ft. lb.
D=Diameter of propeller, ft.
C_T=Thrust coef.=$(T-A)\div\rho n^2D^4$
C_{P_1}=Power coef.=$P\div\rho n^3D^5$.
P=Power=$2\pi\ nQ$ ft. lb. sec.

TABLE XV

PROPELLER NO. 1. PITCH RATIO, 0.7

MODEL C—DEHAVILLAND

CLEARANCE, ⅜ INCH

RADIATOR—WIRE GAUZE

$\frac{1}{2}\rho V^2$	V	N	T	R_a	R_o	A	$T-A$	Q	V/nD	C_T	C_{P_1}
3. 110	50. 90	1, 430	0. 000	0. 890	0. 788	----------	----------	0. 175	1. 065	----------	0. 0252
3. 100	50. 84	1, 616	. 706	. 965	. 785	0. 180	0. 526	. 319	. 941	0. 0189	. 0360
3. 148	51. 26	1, 729	1. 434	1. 045	. 798	. 247	1. 187	. 463	. 855	. 0344	. 0422
3. 138	51. 20	2, 050	2. 646	1. 170	. 795	. 375	2. 271	. 705	. 749	. 0509	. 0496
3. 185	51. 60	2, 340	4. 080	1. 340	. 806	. 534	3. 546	1. 038	. 662	. 0609	. 0559
3. 321	52. 70	2, 661	5. 955	1. 560	. 841	. 719	5. 236	1. 406	. 594	. 0696	. 0587
3. 300	52. 55	2, 944	8. 180	1. 785	. 835	. 950	7. 230	1. 797	. 536	. 0785	. 0613
3. 335	52. 80	3, 226	10. 540	2. 020	. 844	1. 176	9. 364	2. 228	. 491	. 0847	. 0633
3. 358	53. 00	3, 561	13. 450	2. 345	. 850	1. 495	11. 955	2. 787	. 447	. 0886	. 0650
3. 365	53. 10	3, 850	16. 430	2. 660	. 852	1. 808	14. 622	3. 221	. 414	. 0930	. 0643
. 110	9. 60	3, 051	13. 340	1. 545	. 028	1. 517	13. 823	1. 852	. 094	. 1196	. 0588

TABLE XVI

CLEARANCE, 4 INCHES

3. 009	50. 50	1, 474	----------	0. 670	0. 652	----------	----------	0. 159	1. 027	----------	0. 0220
3. 027	50. 67	1, 654	0. 662	. 715	. 656	0. 059	0. 603	. 325	. 919	0. 0210	. 0356
3. 027	50. 67	1, 851	1. 477	. 770	. 656	. 114	1. 363	. 509	. 822	. 0380	. 0446
2. 997	50. 40	2, 085	2. 668	. 850	. 649	. 201	2. 467	. 737	. 725	. 0542	. 0508
3. 128	51. 52	2, 380	4. 145	. 985	. 678	. 307	3. 838	1. 060	. 649	. 0647	. 0561
3. 168	51. 85	2, 682	5. 930	1. 440	. 686	. 454	5. 476	1. 448	. 580	. 0727	. 0604
3. 180	51. 96	2, 978	8. 090	1. 290	. 689	. 601	7. 489	1. 828	. 523	. 0807	. 0619
3. 208	52. 20	3, 263	10. 580	1. 450	. 695	. 755	9. 825	2. 257	. 480	. 0881	. 0636
3. 373	53. 50	3, 602	13. 340	1. 690	. 731	. 959	12. 381	2. 821	. 446	. 0911	. 0652
3. 467	54. 25	3, 899	16. 540	1. 925	. 751	1. 174	15. 366	3. 347	. 418	. 0971	. 0660
. 110	9. 59	3, 066	13. 400	1. 095	. 024	1. 071	12. 329	1. 917	. 094	. 1231	. 0601

TABLE XVII

PROPELLER NO. 2. PITCH RATIO, 0.9

CLEARANCE, ⅜ INCH

3. 102	50. 98	1, 178	----------	0. 855	0. 785	----------	----------	0. 112	1. 299	----------	0. 0251
3. 107	51. 02	1, 588	1. 452	1. 015	. 787	0. 228	1. 224	. 516	. 964	. 0459	. 0606
3. 074	50. 75	1, 387	. 684	. 930	. 779	. 151	. 533	. 297	1. 097	. 0261	. 0458
3. 107	51. 02	1, 819	2. 624	1. 120	. 787	. 333	2. 291	. 772	. 843	. 0653	. 0692
3. 138	51. 30	2, 101	4. 124	1. 290	. 794	. 496	3. 628	1. 172	. 732	. 0775	. 0786
3. 243	52. 13	2, 376	5. 932	1. 485	. 821	. 664	5. 268	1. 591	. 658	. 0880	. 0835
3. 274	52. 38	2, 662	8. 160	1. 715	. 829	. 886	7. 274	2. 040	. 590	. 0968	. 0853
3. 300	52. 60	2, 964	10. 540	1. 965	. 835	1. 130	9. 410	2. 551	. 532	. 1010	. 0861
3. 400	53. 38	3, 240	13. 430	2. 240	. 861	1. 379	12. 051	3. 055	. 494	. 1082	. 0862
3. 428	53. 59	3, 526	16. 540	2. 575	. 868	1. 707	14. 833	3. 655	. 456	. 1125	. 0871
. 114	9. 79	2, 905	13. 300	1. 580	. 029	1. 551	11. 749	2. 231	. 101	. 1311	. 0782

TABLE XVIII

CLEARANCE, 4 INCHES

2. 996	49. 81	1, 181	----------	0. 645	0. 649	----------	----------	0. 137	1. 264	----------	0. 0288
3. 000	49. 83	1, 388	0. 684	. 640	. 650	0. 010	0. 674	. 342	1. 077	0. 0330	. 0519
2. 990	49. 80	1, 574	1. 499	. 740	. 648	. 092	1. 407	. 559	. 949	. 0529	. 0664
3. 037	50. 18	1, 817	2. 668	. 845	. 658	. 187	2. 481	. 827	. 828	. 0700	. 0733
3. 075	50. 50	2, 093	4. 124	. 955	. 666	. 289	3. 835	1. 175	. 724	. 0817	. 0786
3. 177	51. 34	2, 353	5. 954	1. 100	. 688	. 418	5. 536	1. 581	. 654	. 0933	. 0837
3. 264	52. 01	2, 653	8. 204	1. 280	. 707	. 573	7. 631	2. 073	. 588	. 1011	. 0862
3. 350	52. 80	2, 956	10. 580	1. 485	. 725	. 760	9. 820	2. 586	. 536	. 1050	. 0869
3. 410	53. 25	3, 231	13. 400	1. 690	. 739	. 951	12. 449	3. 084	. 495	. 1115	. 0868
3. 500	53. 94	3, 528	16. 540	1. 915	. 758	1. 157	15. 383	3. 699	. 459	. 1137	. 0874
. 150	11. 15	3, 165	16. 560	1. 063	. 032	1. 031	15. 529	2. 840	. 106	. 1450	. 0833

V=Velocity f. p. s.
N=R. P. M.
n=r. p. s.
T=Actual thrust, lb.
R_a=Resistance of model with propeller in action, lb.
R_o=Resistance of model without propeller at same speed as for R_a, lb.

A=Augment of resistance=R_a-R_o.
Q=Torque, ft. lb.
D=Diameter of propeller, ft.
C_T=Thrust coef.=$(T-A)\div\rho n^2D^4$.
C_{P_1}=Power coef.=$P\div\rho n^3D^4$.
P=Power=$2\pi nQ$ ft. lb. sec.

TABLE XIX

PROPELLER NO. 1. PITCH RATIO, 0.7

MODEL C—DEHAVILLAND

CLEARANCE, ⅜ INCH

RADIATOR—SPACE OPEN

$\frac{1}{2}\rho V^2$	V	N	T	R_a	R_o	A	$T-A$	Q	V/nD	C_T	C_{P_1}
2. 820	49. 16	1, 395	0. 001	0. 745	0. 664	----------	----------	0. 103	1. 059	----------	0. 0160
2. 864	49. 60	1, 610	. 684	. 840	. 676	0. 164	0. 520	. 277	. 924	0. 0194	. 0324
2. 909	50. 00	1, 827	1. 521	. 935	. 685	. 250	1. 271	. 451	. 821	. 0368	. 0410
3. 032	51. 04	2, 097	2. 712	1. 085	. 714	. 371	2. 341	. 710	. 730	. 0514	. 0490
3. 124	51. 85	2, 355	4. 080	1. 235	. 736	. 499	3. 581	. 969	. 661	. 0626	. 0532
3. 102	51. 67	2, 680	6. 040	1. 425	. 731	. 694	5. 346	1. 367	. 579	. 0721	. 0579
3. 110	51. 75	2, 971	8. 016	1. 625	. 732	. 893	7. 123	1. 772	. 522	. 0782	. 0611
3. 067	51. 38	3, 258	10. 700	1. 810	. 722	1. 088	9. 612	2. 134	. 473	. 0877	. 0611
3. 150	52. 10	3, 261	10. 630	1. 855	. 743	1. 112	9. 518	2. 156	. 480	. 0868	. 0618
3. 185	52. 43	3, 564	13. 070	2. 105	. 750	1. 355	11. 715	2. 629	. 442	. 0896	. 0631
3. 252	52. 97	3, 951	16. 270	2. 481	. 767	1. 714	14. 556	3. 130	. 402	. 0905	. 0612
. 106	9. 40	3, 068	13. 350	1. 398	. 025	1. 373	11. 977	1. 877	. 092	. 1198	. 0591

TABLE XX

CLEARANCE, 4 INCHES

3. 062	51. 80	1, 504	----------	0. 744	0. 707	----------	----------	0. 134	1. 033	----------	0. 0183
3. 078	51. 91	1, 700	0. 661	. 719	. 641	0. 078	0. 583	. 285	. 916	. 0199	. 0305
3. 119	52. 26	1, 906	1. 522	. 737	. 607	. 130	1. 392	. 488	. 825	. 0378	. 0146
3. 113	52. 22	2, 151	2. 647	. 819	. 606	. 213	2. 434	. 736	. 728	. 0518	. 0492
3. 183	52. 80	2, 398	4. 051	. 925	. 620	. 305	3. 746	1. 016	. 661	. 0643	. 0547
3. 240	53. 28	2, 745	6. 076	1. 069	. 630	. 439	5. 536	1. 448	. 582	. 0737	. 0594
3. 107	51. 87	2, 981	8. 090	1. 155	. 604	. 551	7. 539	1. 784	. 522	. 0827	. 0614
3. 115	51. 95	3, 297	10. 670	1. 335	. 606	. 729	9. 941	2. 232	. 473	. 0891	. 0628
3. 234	52. 94	3, 620	13. 340	1. 530	. 629	. 901	12. 439	2. 690	. 438	. 0925	. 0628
3. 256	53. 11	3, 908	16. 580	1. 710	. 634	1. 076	15. 504	3. 243	. 408	. 0990	. 0650
. 128	10. 34	3, 000	13. 380	1. 045	. 025	1. 020	12. 360	1. 933	. 103	. 1321	. 0649

TABLE XXI

PROPELLER NO. 2. PITCH RATIO, 0.9

CLEARANCE, ⅜-INCH

3. 190	53. 06	1, 237	----------	0. 680	0. 710	----------	----------	0. 108	1. 287	----------	0. 0221
3. 199	53. 18	1, 421	0. 661	. 858	. 752	0. 106	0. 555	. 282	1. 123	0. 0273	. 0437
3. 140	52. 69	1, 644	1. 544	. 964	. 754	. 212	1. 332	. 506	. 962	. 0490	. 0585
3. 177	52. 99	1, 888	2. 648	1. 045	. 742	. 303	2. 345	. 839	. 842	. 0654	. 0735
3. 021	51. 63	2, 118	4. 169	1. 095	. 734	. 361	3. 808	1. 169	. 732	. 0831	. 0805
3. 171	52. 20	2, 391	5. 978	1. 245	. 748	. 497	5. 481	1. 566	. 655	. 0927	. 0831
3. 278	53. 05	2, 692	8. 072	1. 470	. 773	. 697	7. 375	2. 007	. 592	. 0983	. 0841
3. 239	52. 67	3, 002	10. 580	1. 735	. 762	. 973	9. 607	3. 574	. 526	. 1030	. 0867
3. 250	52. 90	3, 260	13. 420	1. 985	. 767	1. 218	12. 202	3. 008	. 487	. 1112	. 0861
3. 391	54. 05	3, 550	16. 510	2. 295	. 800	1. 495	15. 015	3. 546	. 457	. 1155	. 0857
3. 299	53. 31	2, 983	10. 580	1. 745	. 778	. 967	9. 613	2. 497	. 536	. 1047	. 0834

TABLE XXII

CLEARANCE, 4 INCHES

2. 842	49. 65	1, 176	----------	0. 545	0. 553	----------	----------	0. 054	1. 267	----------	0. 0120
2. 948	50. 58	1, 411	0. 661	. 615	. 573	0. 042	0. 619	. 285	1. 075	0. 0304	. 0439
2. 960	50. 73	1, 610	1. 477	. 675	. 576	. 099	1. 378	. 508	. 944	. 0519	. 0601
2. 992	50. 99	1, 870	2. 669	. 775	. 582	. 193	2. 476	. 812	. 818	. 0693	. 0713
2. 965	50. 77	2, 113	4. 169	. 840	. 577	. 263	3. 906	1. 129	. 721	. 0852	. 0776
3. 070	51. 65	2, 396	5. 978	. 975	. 590	. 385	5. 593	1. 570	. 647	. 0952	. 0839
3. 110	52. 02	2, 683	8. 025	1. 125	. 606	. 519	7. 506	2. 047	. 582	. 1016	. 0871
3. 090	51. 78	2, 973	10. 620	1. 280	. 601	. 679	9. 941	2. 487	. 521	. 1097	. 0862
3. 467	54. 85	3, 300	13. 450	1. 510	. 674	. 836	12. 614	3. 097	. 498	. 1129	. 0871
3. 530	55. 34	3, 576	16. 490	1. 705	. 686	1. 019	15. 471	3. 658	. 465	. 1180	. 0876

V=Velocity f. p. s.
N=R. P. M.
n=r. p. s.
T=Actual thrust, lb.
R_a=Resistance of model with propeller in action, lb.
R_o=Resistance of model without propeller at same speed as for R_a, lb.
A=Augment of resistance=R_a-R_o.
Q=Torque, ft. lb.
D=Diameter of propeller, ft.
C_T=Thrust coef.=$(T-A)\div\rho\ n^2D^4$.
C_{P_1}=Power coef.=$P\div\rho\ n^3D^5$.
P=Power=$2\ \pi\ nQ$ ft. lb. sec.

TABLE XXIII

PROPELLER NO. 1. PITCH RATIO, 0.7

MODEL C—DEHAVILLAND

CLEARANCE, ⅜ INCH

RADIATOR—CLOSED

$\frac{1}{2}\rho V^2$	V	N	T	R_a	R_o	A	$T-A$	Q	V/nD	C_T	C_{P_1}
3.089	51.20	1,448	----------	1.100	0.958	----------	----------	0.127	1.060	----------	0.0181
3.129	51.60	1,623	----------	1.055	.952	----------	----------	.292	.952	----------	.0333
3.071	51.15	1,624	0.684	1.170	.952	0.218	0.466	.286	.946	0.0169	.0326
3.071	51.15	1,802	1.433	1.275	.952	.323	1.110	.449	.851	.0328	.0416
3.137	51.75	2,073	2.646	1.465	.973	.492	2.154	.698	.748	.0481	.0490
3.185	52.20	2,348	4.057	1.655	.987	.668	3.389	.986	.667	.0591	.0540
3.300	53.10	2,674	6.019	1.945	1.023	.922	5.097	1.358	.597	.0685	.0573
3.260	52.90	2,956	8.138	2.150	1.010	1.140	6.998	1.723	.536	.0774	.0598
3.260	52.90	3,261	10.580	2.465	1.010	1.455	9.125	2.152	.487	.0829	.0614
3.343	53.60	3,580	13.410	2.835	1.035	1.800	11.610	2.578	.449	.0875	.0610
3.382	53.90	3,879	16.530	3.315	1.048	2.267	14.263	3.091	.418	.0916	.0624

TABLE XXIV

CLEARANCE, 4 INCHES

3.080	51.79	1,531	----------	0.830	0.900	----------	----------	0.192	1.015	----------	0.0237
3.084	51.84	1,484	----------	.835	.903	----------	----------	.145	1.049	----------	.0202
3.088	51.94	1,670	0.661	.895	.903	----------	0.661	.340	.933	0.0232	.0376
3.180	52.68	2,128	2.679	1.105	.928	0.177	2.502	.745	.743	.0542	.0507
3.303	53.68	2,692	5.955	1.485	.965	.520	5.435	1.427	.598	.0735	.0606
3.343	54.03	3,290	10.580	1.960	.976	.984	9.596	2.236	.492	.0869	.0636
3.409	54.54	3,909	16.620	2.625	.995	1.630	14.990	3.300	.418	.0962	.0666
3.422	54.65	3,593	13.330	2.275	.998	1.277	12.053	2.744	.455	.0913	.0655
3.343	54.02	2,969	8.025	1.690	.976	.714	7.311	1.824	.546	.0814	.0638
3.199	52.84	2,385	3.970	1.265	.934	.331	3.639	1.073	.664	.0628	.0582
3.199	52.84	1,888	1.477	1.000	.934	.066	1.411	.561	.839	.0389	.0486

TABLE XXV

PROPELLER NO. 2. PITCH RATIO, 0.9

CLEARANCE, ⅜ INCH

3.353	53.91	1,258	----------	1.040	1.040	----------	----------	0.1367	1.286	----------	0.0326
3.353	53.98	1,615	1.323	1.420	1.040	0.380	0.943	.4702	1.003	0.0354	.0554
3.353	54.03	1,893	2.646	1.575	1.040	.535	2.111	----------	.856	.0577	----------
3.110	52.44	1,889	2.648	1.439	.965	.474	2.174	.0818	.833	.0606	.0691
3.180	52.71	2,146	4.124	1.657	.990	.667	3.457	.1353	.734	.0744	.0758
3.190	53.10	2,430	5.856	1.870	.992	.878	4.978	.1518	.656	.0838	.0804
3.295	52.90	2,661	8.000	2.095	1.023	1.072	6.928	.2846	.596	.0933	.0871
3.318	53.10	2,970	10.780	2.440	1.029	1.411	9.369	.3514	.536	.1015	.0865
3.309	53.07	2,963	10.590	2.435	1.026	1.409	9.181	.3487	.537	.1000	.0863
3.327	53.20	3,253	13.410	2.785	1.032	1.753	11.657	.4264	.490	.1053	.0875
3.340	53.33	3,536	16.550	3.245	1.036	2.209	14.341	.4990	.452	.1094	.0867

TABLE XXVI

CLEARANCE 4 INCHES

3.137	52.36	1,226	----------	0.885	0.916	----------	----------	0.138	1.280	----------	0.0284
3.160	52.54	1,422	0.662	.920	.923	----------	0.662	.347	1.108	0.0322	.0531
3.177	52.73	1,631	1.477	1.005	.928	0.077	1.400	.576	.970	.0518	.0671
3.190	52.83	1,852	2.646	1.105	.932	.173	2.473	.833	.856	.0710	.0751
3.248	53.30	2,142	4.123	1.275	.948	.327	3.796	1.233	.746	.0815	.0832
3.353	54.17	2,418	5.953	1.485	.979	.506	5.447	1.639	.672	.0918	.0867
3.340	54.00	2,700	8.136	1.690	.975	.715	7.421	2.061	.600	.1001	.0873
3.374	54.30	2,977	10.590	1.940	.986	.954	9.636	2.545	.547	.1070	.0888
3.357	54.17	3,268	13.400	2.225	.981	1.244	12.156	3.067	.497	.1120	.0887
3.480	55.15	3,558	16.510	2.595	1.016	1.579	14.931	3.709	.463	.1152	.0899

V=Velocity f. p. s.
N=R. P. M.
n=r. p. s.
T=Actual thrust, lb.
R_a=Resistance of model with propeller in action, lb.
R_o=Resistance of model without propeller at same speed as for R_a, lb.

A=Augment of resistance=R_a-R_o.
Q=Torque, ft. lb.
D=Diameter of propeller, ft.
C_T=Thrust coef.=$(T-A)\div\rho n^2D^4$.
C_{P_1}=Power coef.=$P\div\rho n^3D^5$.
P=Power=$2\pi nQ$ ft., lb. sec.

REPORT No. 236

TESTS ON AIRPLANE FUSELAGES, FLOATS AND HULLS

By WALTER S. DIEHL
Bureau of Aeronautics, Navy Department

REPORT No. 236

TESTS ON AIRPLANE FUSELAGES, FLOATS AND HULLS

By Walter S. Diehl

SUMMARY

This report is a compilation of test data on airplane fuselages, nacelles, airship cars, seaplane floats, and seaplane hulls, prepared by the Bureau of Aeronautics, at the request of the National Advisory Committee for Aeronautics. The discussion of the data includes the derivation of a scale correction curve to be used in obtaining the full scale drag. Composite curves of drag and L/D for floats and hulls are also given.

INTRODUCTION

In order to make an accurate estimate of the probable performance of an airplane, the parasite drag must be known. When wind tunnel test data are not available, this parasite drag must be obtained by some process of summation, and in such a process one of the largest and most uncertain items is the drag of the fuselage, or similar parts, such as the nacelles, hull, or floats. The usual practice is to compare the desired design with other and similar designs for which test data are available.

In 1922 the Bureau of Aeronautics compiled all of the wind tunnel test data then available on fuselages, hulls, nacelles, and floats, into a form which was convenient for ready reference. This compilation was of such value that the National Advisory Committee for Aeronautics has seen fit to request its release for publication as the first of a series of reports, giving wind tunnel test data of this type in condensed form.

For convenience in reference the models have been divided into seven groups, each designated by a letter as follows:

A.—Airplane fuselages.
B.—Airplane fuselages with appendages.
C.—Nacelles.
D.—Fins.
E.—Airship cars.
F.—Seaplane floats.
G.—Seaplane hulls.

Each model is designated by a group letter and a number, thus A1, i. e., airplane fuselage No. 1, or F4, float No. 4.

TEST DATA

For each model the source of the test data, the size of the model, and the test speed are given in addition to the test data. Whenever practical, the drag is given in pounds and pounds per square foot at some specified wind speed.

The data from British tests are frequently in the form of normal force Z and longitudinal force X. When necessary these can be converted to lift and drag by the usual formulas:

$$L = Z \cos\theta - X \sin\theta \qquad (1)$$

$$D = X \cos\theta + Z \sin\theta$$

Where θ is the angle of pitch.

Corrections for pressure drop along the wind tunnel axis have not been applied to any of the test data in this report. Since it would rarely be more than the experimental error, the omission of this correction is apparently justified for all models which deviate appreciably from the conventional streamline forms. For example, on the float F1 the maximum possible correction for pressure drop at 58.7 f. p. s. is about 0.0007 pound, while the actual correction is somewhat less, due to location of model during tests. Since the measured drag of F1 at 58.7 f. p. s. was 0.0627 pound, the correction would be of the order of 1 per cent.

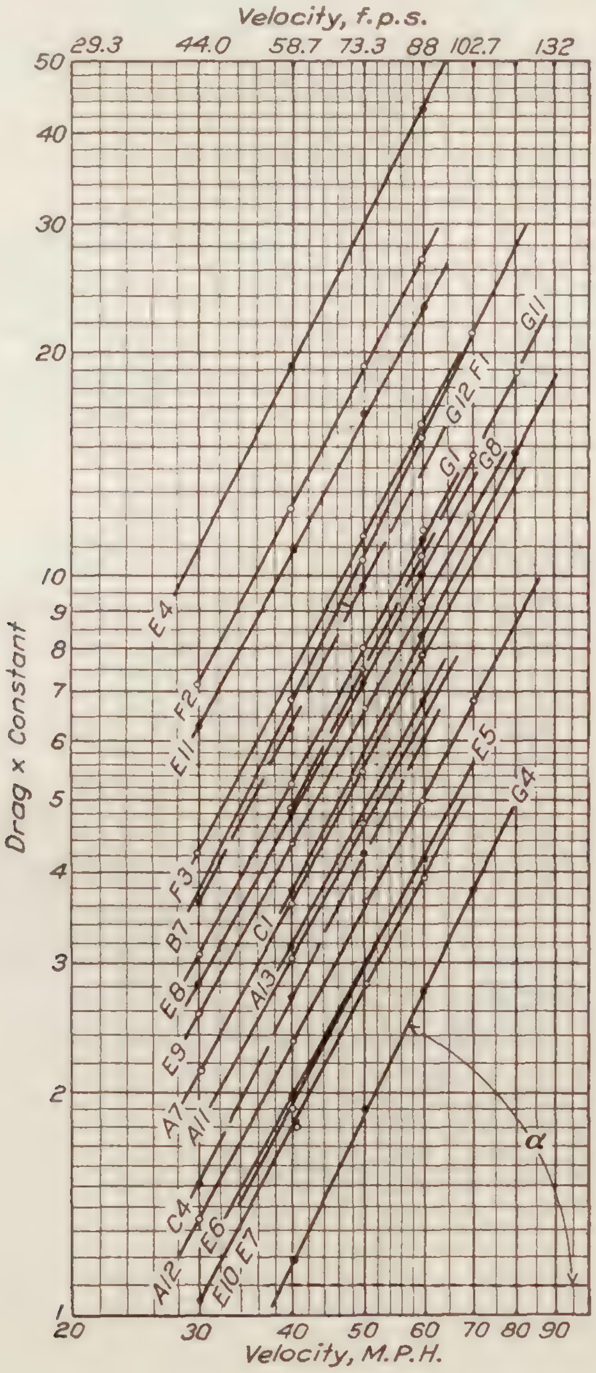


FIG. 1

SCALE EFFECT

Taking the product of the velocity V by some characteristic length l as the "scale" the lift may be assumed to vary as the square of the scale. That is:

$$L = K_L\ (Vl)^2 \tag{3}$$

where K_L is a constant for each model.

The drag does not vary as the square, but as some lesser power of the scale. Figure 1 is a logarithmic plot or drag against speed for all models tested at more than one speed. The slopes of the lines with the corresponding exponents are given in the following table:

VELOCITY EXPONENT IN THE DRAG EQUATION

$D=KV^n$

Model designation	α	n $\tan \alpha$
A7	61.7	1.86
A11	61.3	1.86
A12	62.2	1.90
A13	61.6	1.85
B7	63.7	2.02
C1	62.7	1.94
C4	63.0	1.96
E4	63.0	1.96
E5	61.0	1.80
E6	61.8	1.86
E7	62.3	1.90
E8	61.8	1.86
E9	61.4	1.91
E10	62.3	1.90
E11	61.8	1.86
F1	62.7	1.94
F2	62.3	1.90
F3	62.4	1.91
G1	61.8	1.86
G4	64.0	2.05
G8	61.2	1.82
G11	62.5	1.92
G12	62.7	1.94
Average	62.2	1.90

The average value of the exponent so found is $n=1.90$. While this strictly applies to the velocity only, it may be assumed for variation in length also. The drag equation may therefore be written as

$$D=K_D\,(Vl)^{1.9} \tag{4}$$

where K_D is a constant for each model.

It will probably be found more convenient to use instead of equation (4):

$$D=K_s \cdot D_m\left(\frac{V\,l}{V_m l_m}\right)^2 \tag{5}$$

where K_s is the scale correction factor given on Figure 2, D_m the observed model drag at $V_m l_m$ and D the full scale drag at Vl.

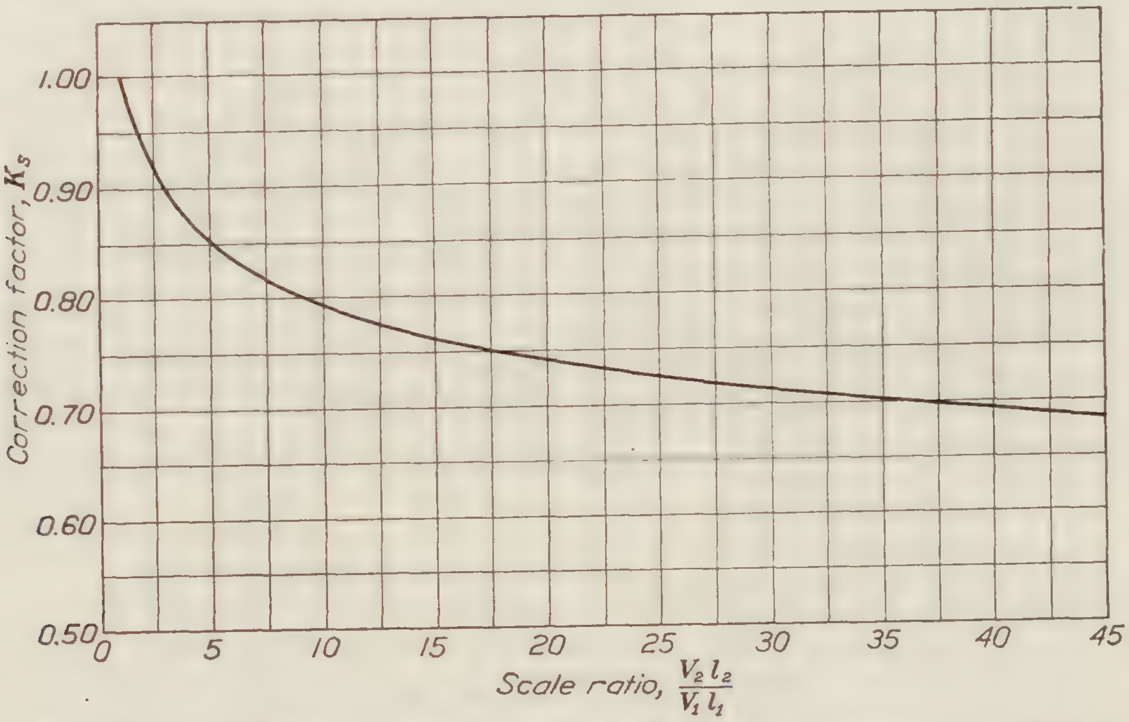


FIG. 2.—Drag correction factors for fuselages, hulls, floats, etc. Based on the assumption that $D \propto V^{1.90}$
$D_2=K_s D_1\left(\frac{V_2 l_2}{V_1 l_1}\right)^2$ Where $D_1=$ Drag at $V_1 l_1$ and $D_2=$ Drag at $V_2 l_2$

In converting model data to full scale values, any length on the model such as maximum diameter, overall length, etc., may be used to determine the scale, provided that the same geometrical length is used for model and full scale. The use of overall length is recommended, however.

The square of a length has the dimensions of area so that the maximum cross-sectional area may be used instead of l^2 if desired.

COMPOSITE CURVES FOR FLOATS AND HULLS

The drag curves for different floats and hulls differ so little, one from another, that a composite curve may be drawn to represent within comparatively narrow limits the drag for all such models. This curve is given on Figure 3. Knowing the drag for 0° pitch of the deck line, the drag for any normal pitch angle is readily obtained from this curve.

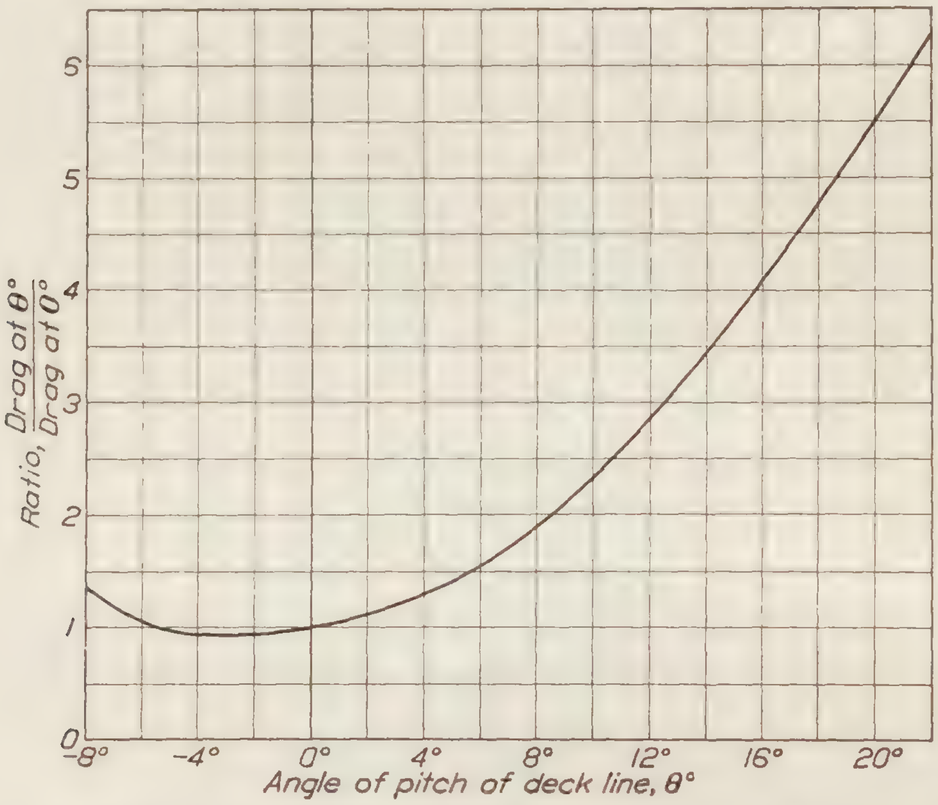


FIG. 3.—Composite resistance curve for seaplane floats and hulls

The lift curves are also similar, so that a composite curve for L/D may be drawn as in Figure 4.

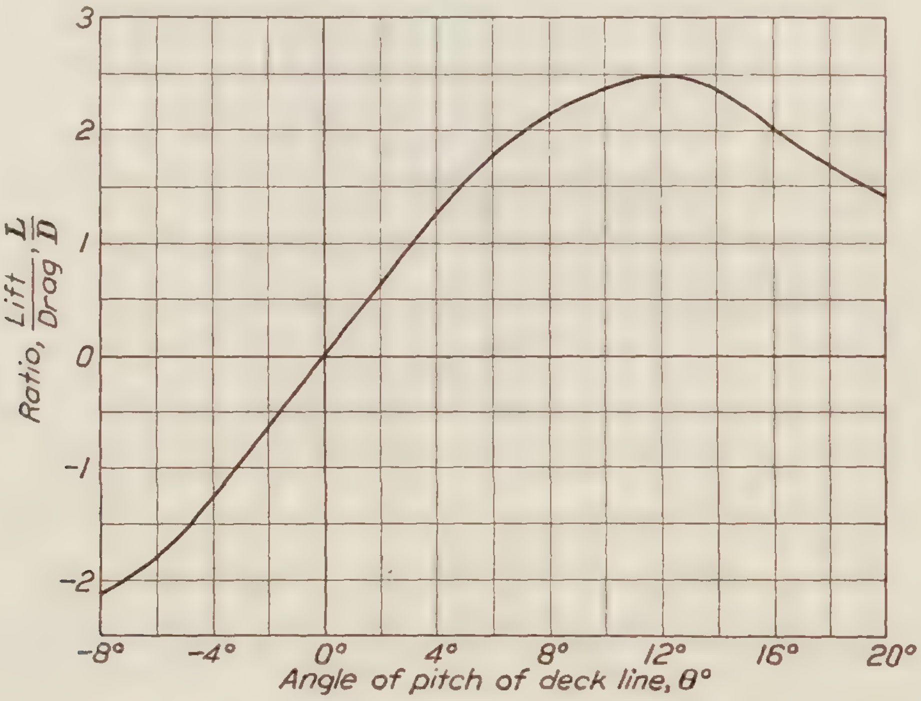
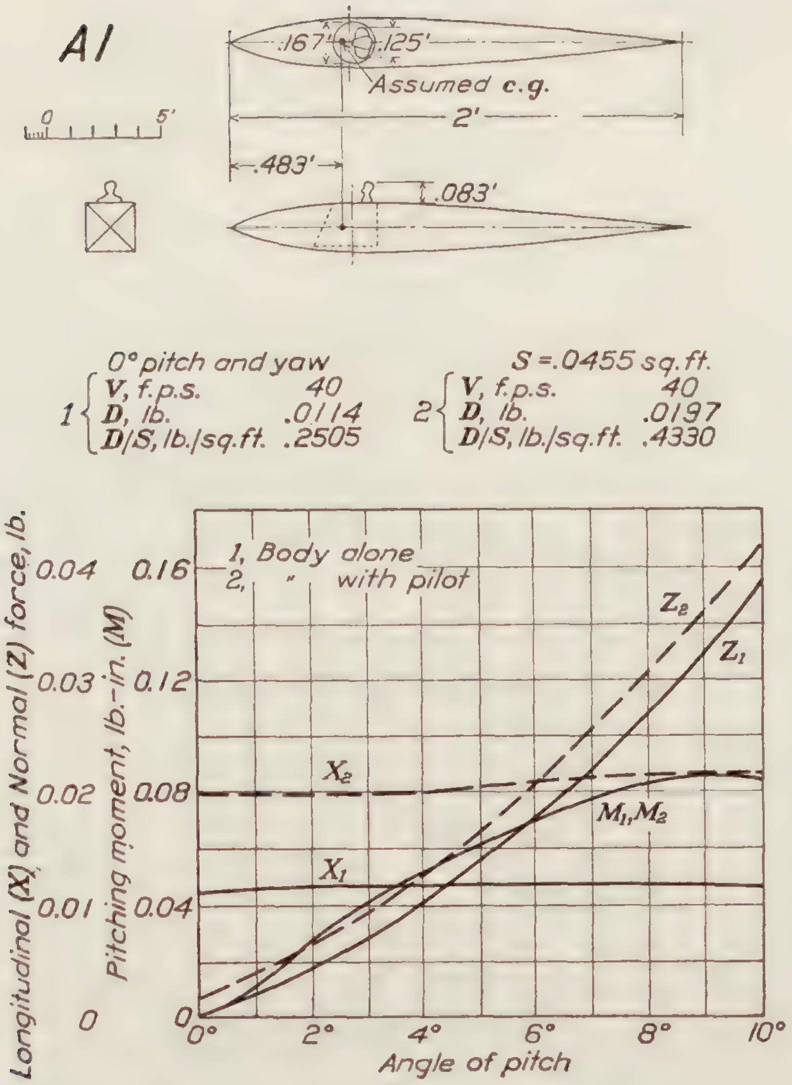


FIG. 4.—Composite L/D curve for floats and hulls

The curves of Figures 3 and 4 apply to any form which approximates to a streamline and which does not have too many appendages. From the limited data available there is reason to believe that the same, or at any rate similar, curves will apply to all body lines of the average or better types.

A1

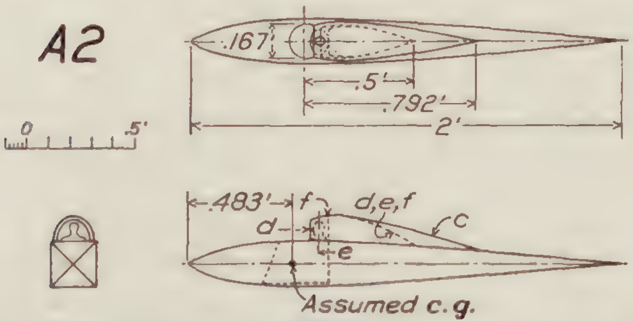


0° pitch and yaw S = .0455 sq. ft.

	1	2
V, f.p.s.	40	40
D, lb.	.0114	.0197
D/S, lb./sq.ft.	.2505	.4330

Forces and moments in pitch on an airplane fuselage. V=40 f. p. s. (Ref. R. and M. No. 112)

A2

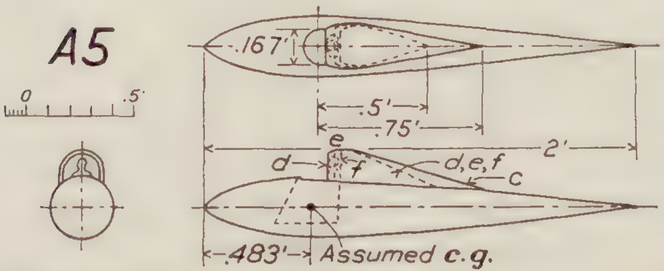


0° pitch and yaw V = 40 f.p.s.

	D, lb.
a, Model without wind shield or pilot	.0114
b, " with pilot, no wind shield	.0197
c, " " long wind shield aft	.0254
d, " " short " " "	.0257
e, " " " " " ", front cut back to e	.0217
f, " " " " " ", " " " f	.0265

Drag on an airplane fuselage. V=40 f. p. s. (Ref. R. and M. No. 112)

A5

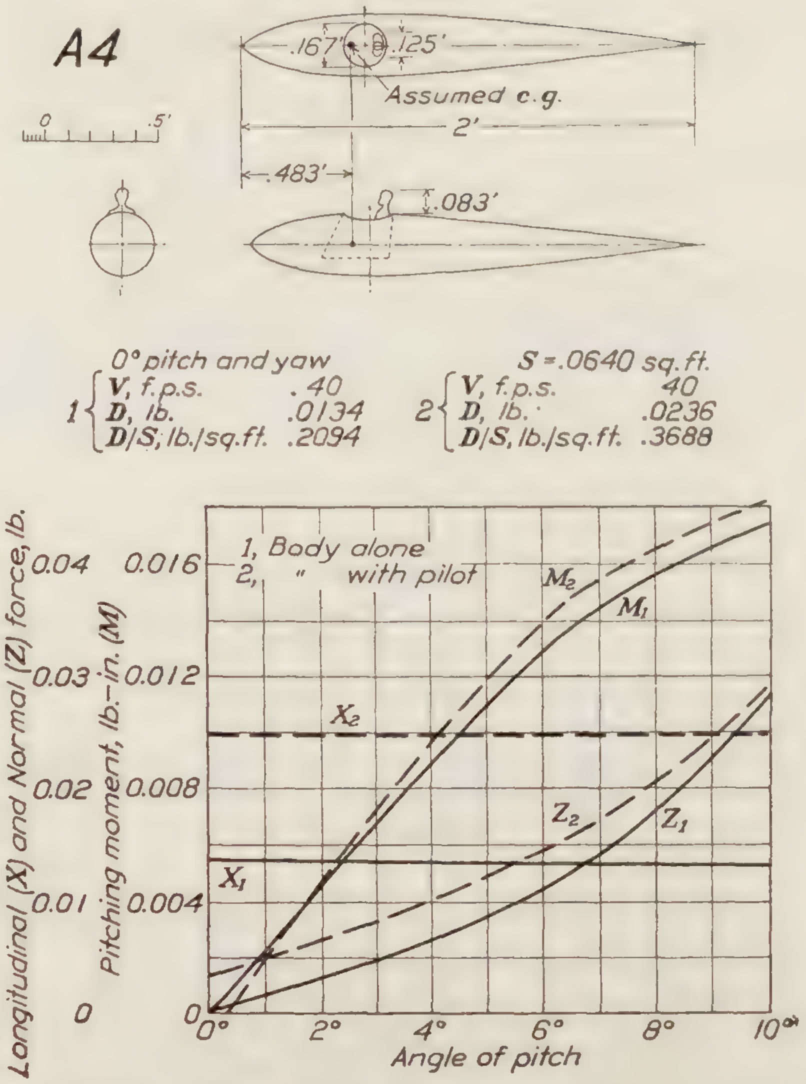


0° pitch and yaw V = 40 f.p.s.

	D, lb.
a, Model without wind shield or pilot	.0134
b, " with pilot, no wind shield	.0246
c, " " long wind shield aft	.0256
d, " " " " "	.0252
e, " " " " " ", front cut back to e	.0272
f, " " " " " ", " " " f	.0296

Drag on airplane fuselage. V=40 f. p. s. (Ref. R. and M. No. 112)

A4

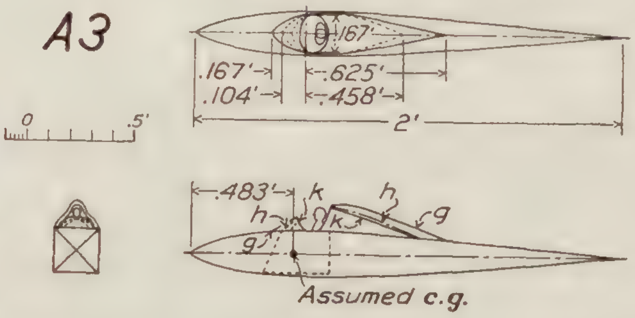


0° pitch and yaw S = .0640 sq. ft.

	1	2
V, f.p.s.	40	40
D, lb.	.0134	.0236
D/S, lb./sq.ft.	.2094	.3688

Forces and moments in pitch on an airplane fuselage V=40 f. p. s. (Ref. R. and M. No. 112)

A3

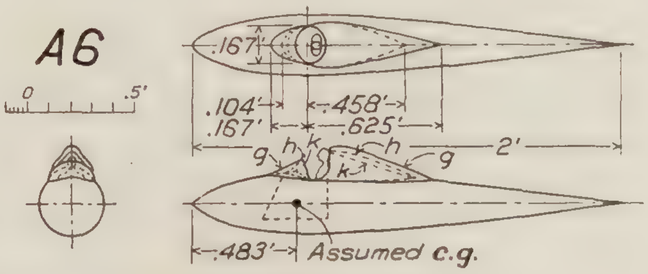


0° pitch and yaw V = 40 f.p.s.

	D, lb.
a, Model without wind shield or pilot	.0114
b, " with pilot, no wind shield	.0197
g, " " wind shield "g-g"	.0206
h, " " " " "h-h"	.0242
k, " " " " "k-k"	.0336

Drag on an airplane fuselage. V=40 f. p. s. (Ref. R. and M. No. 112)

A6

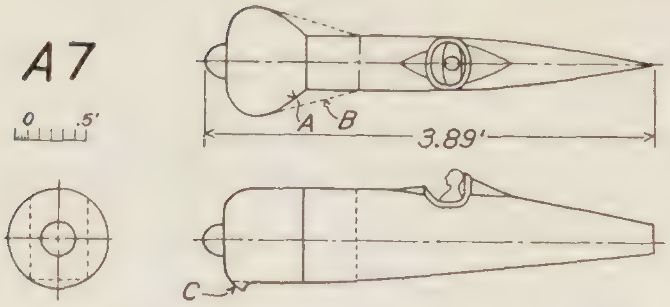


0° pitch and yaw V = 40 f.p.s.

	D, lb.
a, Model without wind shield or pilot	.0134
b, " with pilot, no wind shield	.0246
g, " " wind shield "g-g"	.0225
h, " " " " "h-h"	.0242
k, " " " " "k-k"	.0272

Drag on airplane fuselage. V=40 f. p. s. (Ref. R. and M. No. 112)

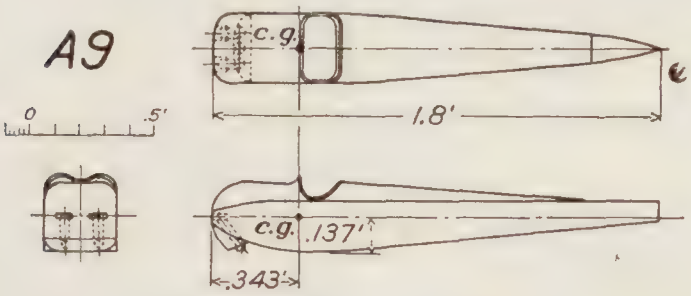
A7



0° pitch and yaw	V, f.p.s.	44.0	58.7	73.3	88.0
Original model "A"	D, lb.	.2850	.4750	.7280	1.0150
S=.6750 sq.ft.	D/S, lb./sq.ft.	.4222	.7037	1.0785	1.5037
Fairing "B" added	D, lb.	.2150	.3630	.5460	.7830
S=.6750 sq.ft.	D/S, lb./sq.ft.	.3185	.5378	.8089	1.1600
Fairing "C" removed	D, lb.	.2000	.3420	.5250	.7450
S=.6620 sq.ft.	D/S, lb./sq.ft.	.3021	.5166	.7931	1.1254

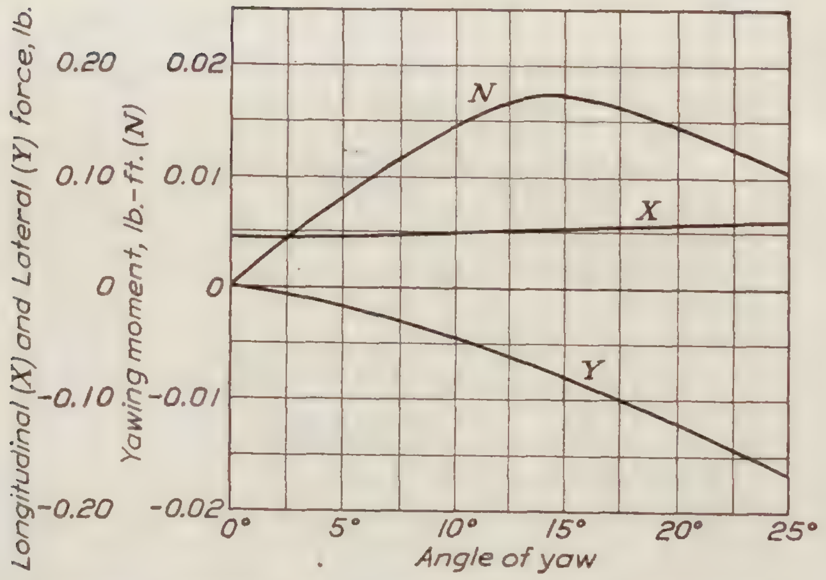
Drag on a Navy speed scout seaplane fuselage. (Ref. W. T. R. No. 20)

A9



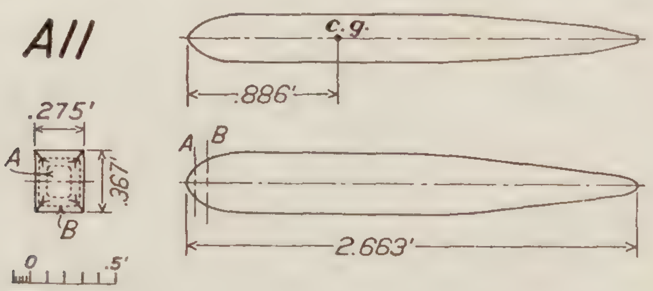
0° pitch and yaw S=.0870 sq.ft.

V, f.p.s.	40
D, lb.	.0443
D/S, lb./sq.ft.	.5100



Forces and moments in yaw on fuselage of Sopwith biplane-type D^{s}. 0° pitch. V=40 f. p. s. (Ref. R. and M. No. 153)

A11

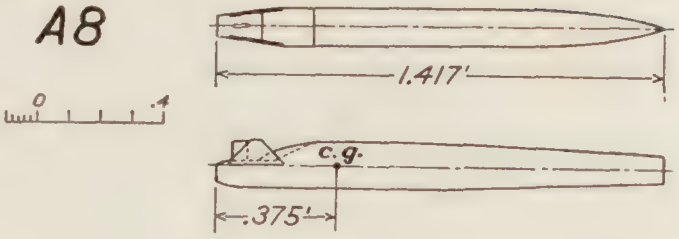


0° pitch and yaw S=.1012 sq.ft.

V, f.p.s.	35	40	50
D, lb.	.0256	.0304	.0466
D/S, lb./sq.ft.	.2530	.3004	.4605

Drag on an airplane fuselage, Bristol Pullman (B). (Ref R. and M. No. 644)

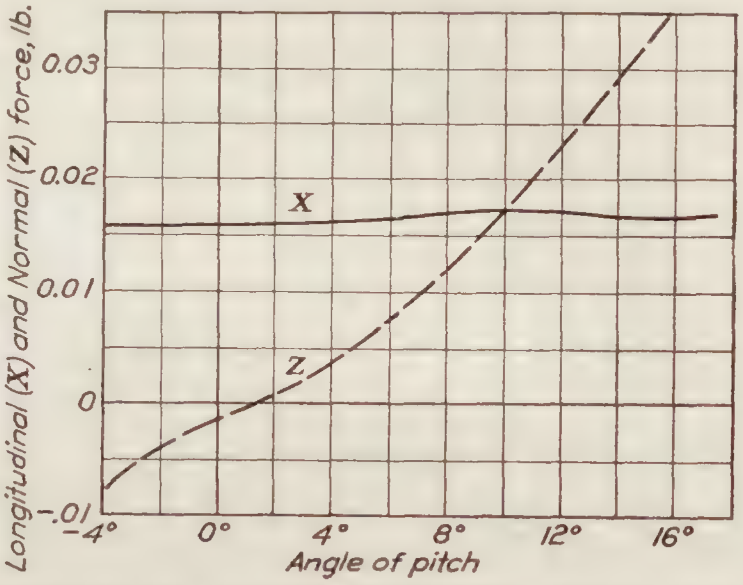
A8



S=.0173 sq.ft.

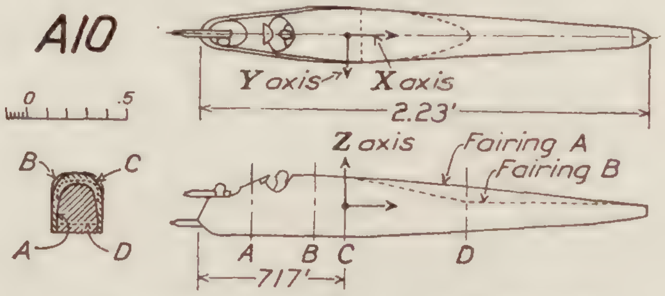
0° pitch and yaw

V, f.p.s.	40
D, lb.	.0159
D/S, lb./sq.ft.	.9200



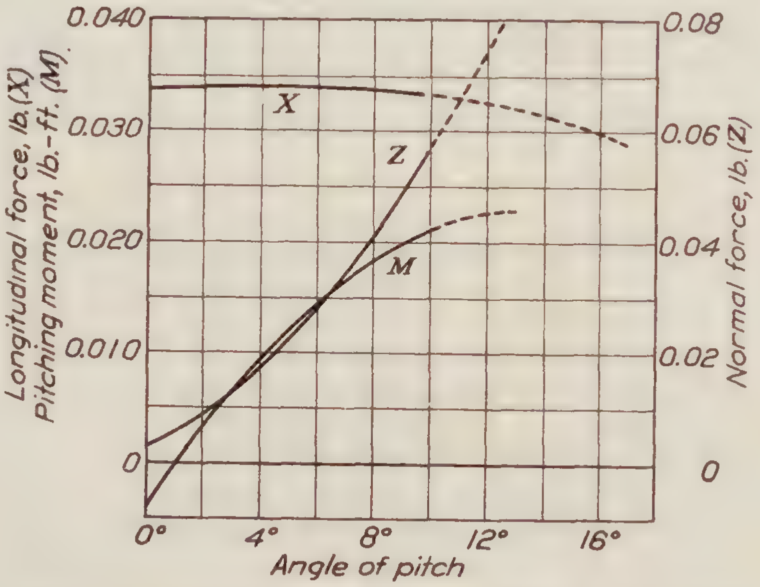
Forces and drag on model-seaplane fuselage. (Ref. R. and M No. 199)

A10

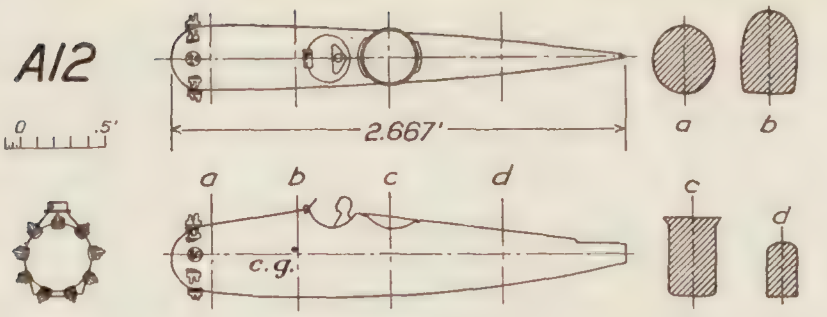


0° pitch and yaw S=.0780 sq.ft.

V, f.p.s.	40	V, f.p.s.	40
Fairing "A"		Fairing "B"	
D, lb.	.0331	D, lb.	.0340
D/S, lb./sq.ft.	.4250	D/S, lb./sq.ft.	.4360



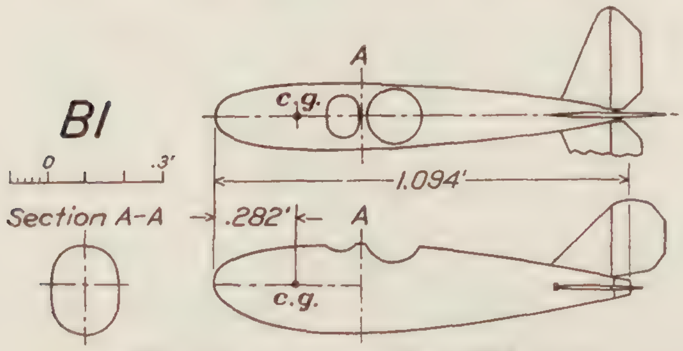
Forces and moments in pitch on airplane fuselage F-E-7 model with fairing "A". V=40 f. p. s. (Ref. R. and M. No. 153)



0° pitch and yaw V = 40 f.p.s. D = .0384 lb.
1, Body without eng., pilot or wind shield, all holes faired - - - -
2, (1) with pilot in place - - - - - - - - - - - - - - - D = .0484 lb.
3, (2) " wind shield in place - - - - - - - - - - D = .0609 lb.
4. Complete as shown, with engine - - - - - - - D = .1540 lb.

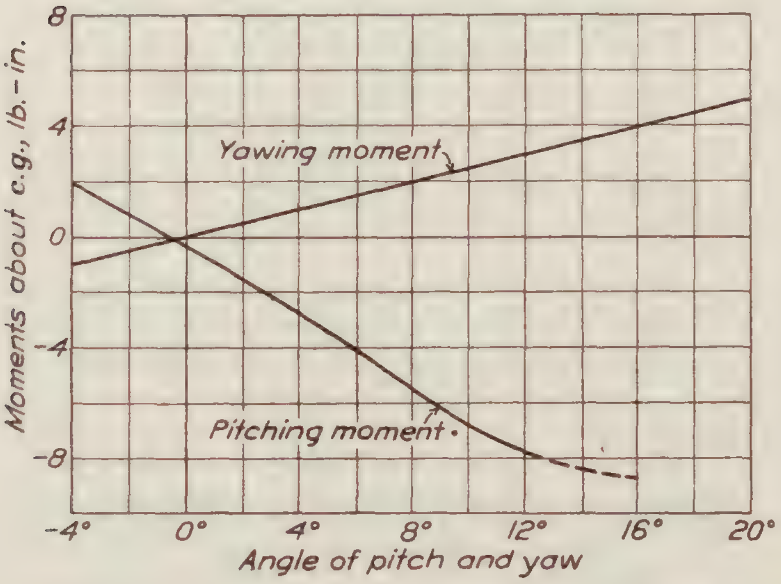
4	V, f.p.s. - - -	44.0	58.7	73.3	88.0	102.7
Combination 1	D, lb. - - - -	.136	.237	.365	.500	.680
" 2	D/S, lb./sq.ft.	.442	.783	1.200	1.718	2.235

Drag on "Weasel" airplane fuselage. (Ref. R. and M. No. 465)

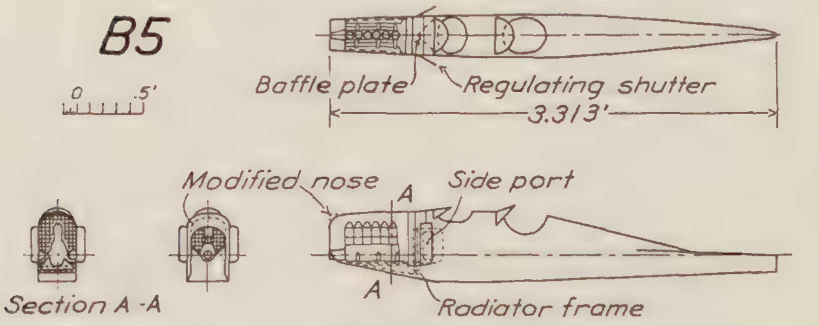


−2° pitch S = .0506 sq.ft.

V, f.p.s.	58.7	88.0
D, lb.	.0123	.0330
D/S, lb./sq.ft.	.2430	.6522

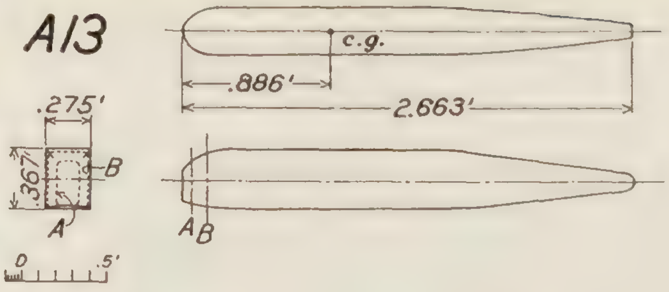


Moments about $c.\ g.$ of Kirkham triplane-speed-scout fuselage. V=58.7 f. p. s. (Ref. W. T. R. No. 73)



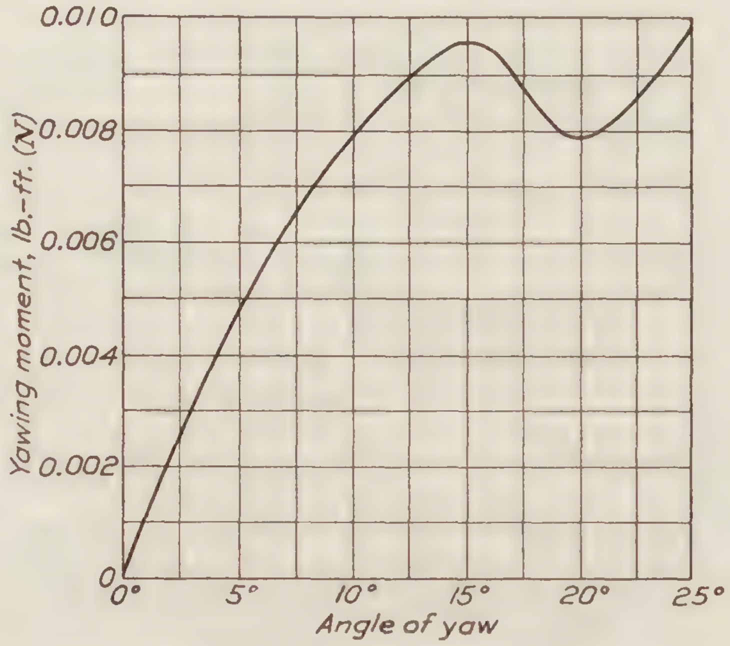
(A) Original model
All openings closed, D = .1157 lb.
Side ports (only) closed, D = .1226 lb.
Inlet opening closed:
shutter, 12°, D = .1316 lb.
" " 25° D = .1698 lb.
(B) Modified model (square nose)
All openings closed, D = .1508 lb.
Side ports (only) closed, D = .1644 lb.
Side ports open, shutters removed, D = .1630 lb.
(C) Radiator drag, $D = KSV^2$, K = .00075, S = sq.ft., V = f.p.s.

Drag on fuselage of RE-7 airplane with shutters. V=40 f. p. s. (Ref. R. and M. No. 221)

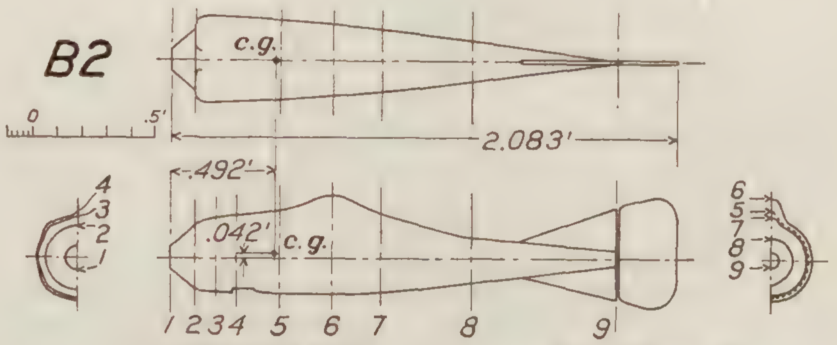


0° pitch and yaw S = .1012 sq.ft.

V, f.p.s.	35	40	50
D lb.	.0276	.0315	.0482
D/S, lb./sq.ft.	.2727	.3113	.4763

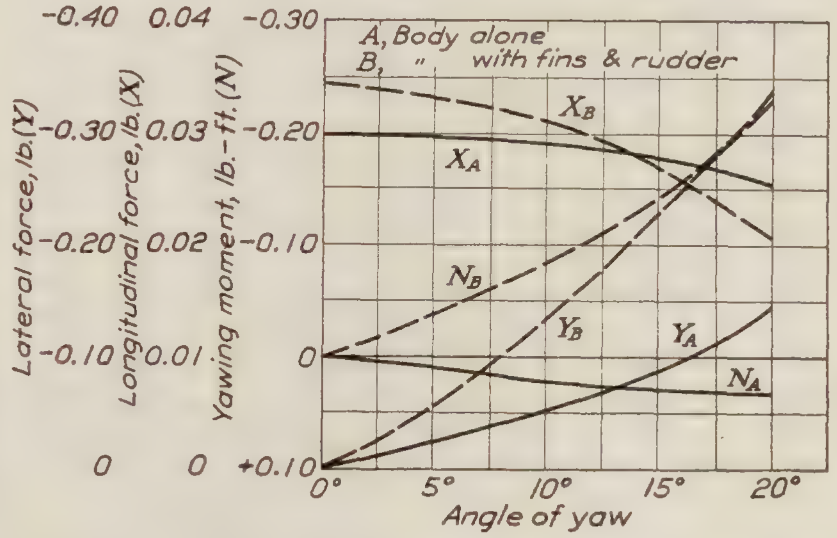


Yawing moment about $c.\ g.$ of airplane fuselage of Bristol Pullman (A). V=50 f. p. s. (Ref. R. and M. No. 644)



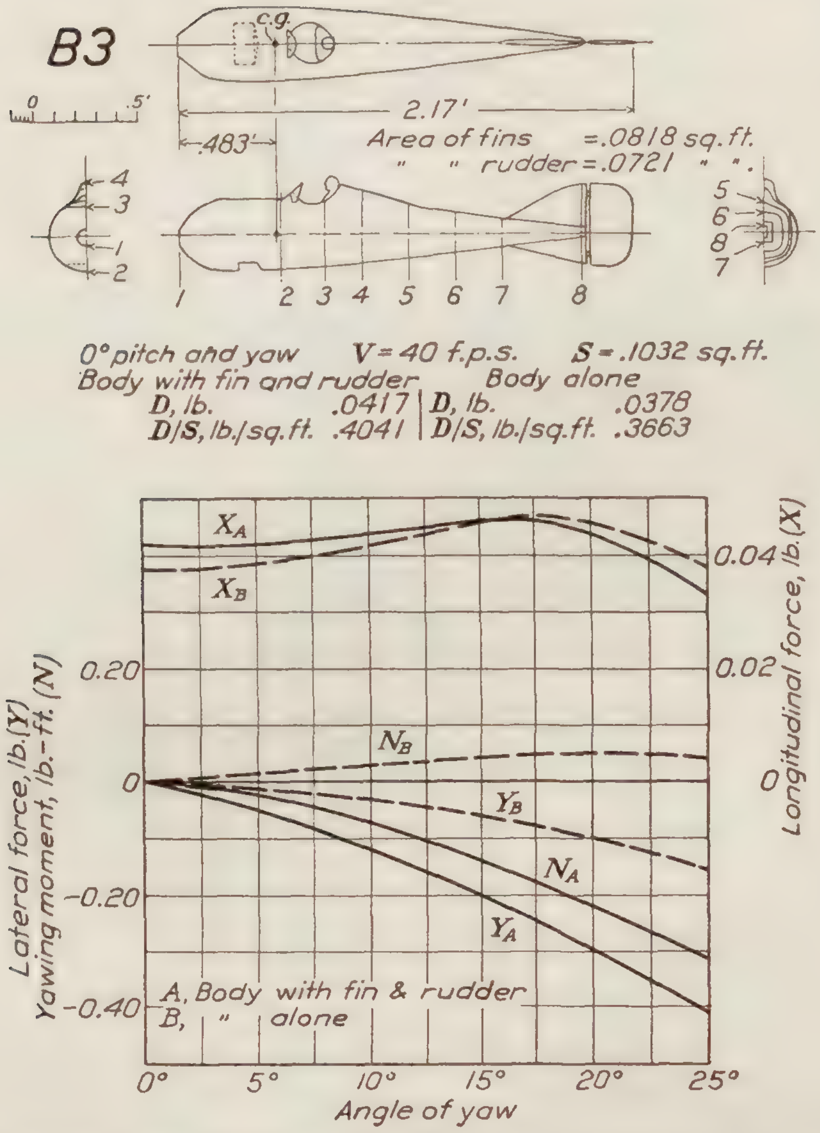
0° pitch and yaw S = .1280 sq.ft.

A	V, f.p.s.	40	B	V, f.p.s.	40
	D, lb.	.0296		D, lb.	.0343
	D/S, lb./sq.ft.	.2313		D/S, lb./sq.ft.	.2680



Forces and moment in yaw on fuselage of SE-4 airplane. V=40 f. p. s. (Ref. R. and M. No. 112)

B3

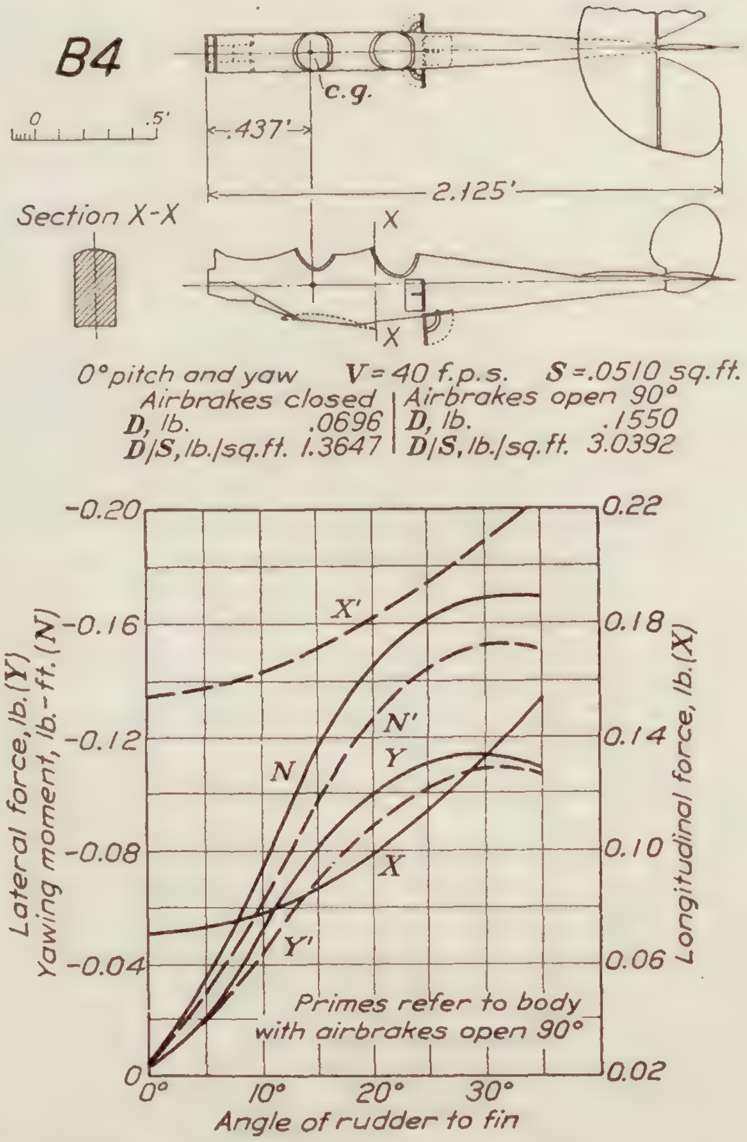


0° pitch and yaw $V=40$ f.p.s. $S=.1032$ sq.ft.

Body with fin and rudder		Body alone	
D, lb.	.0417	D, lb.	.0378
D/S, lb./sq.ft.	.4041	D/S, lb./sq.ft.	.3663

Forces and moments on fuselage of SE–4a airplane. V=40 f. p. s. (Ref. R. and M. No. 153)

B4

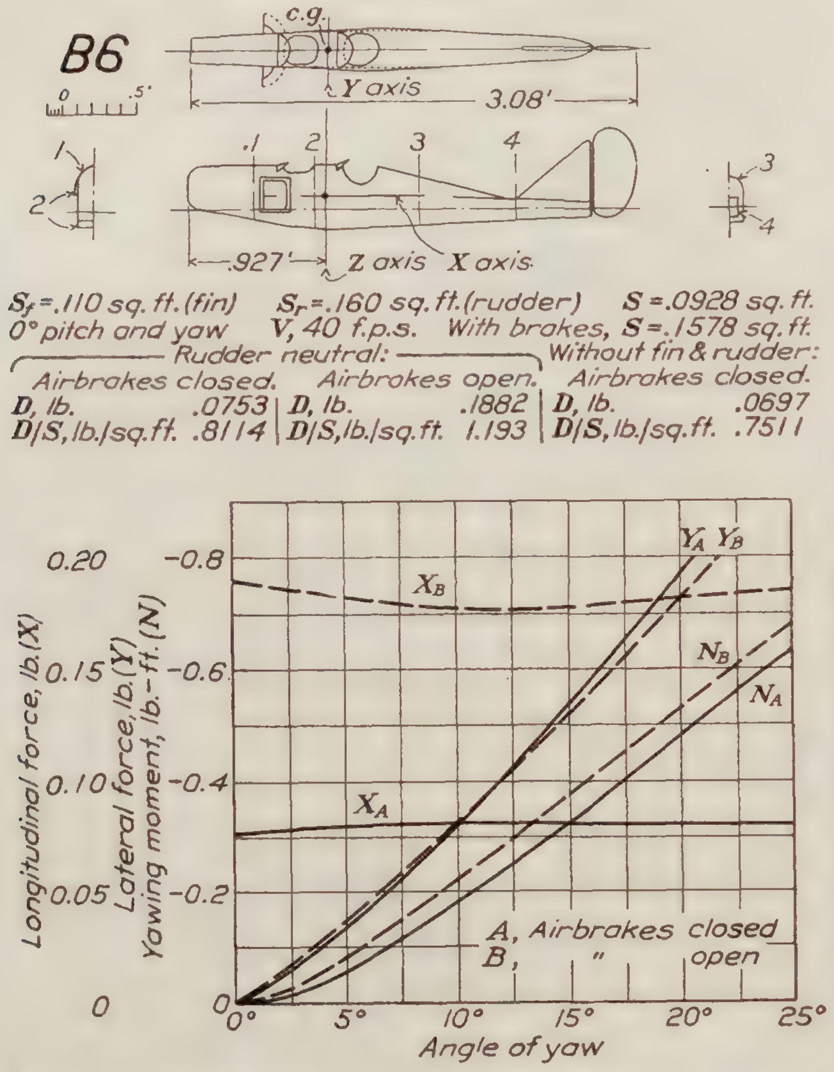


0° pitch and yaw $V=40$ f.p.s. $S=.0510$ sq.ft.

Airbrakes closed		Airbrakes open 90°	
D, lb.	.0696	D, lb.	.1550
D/S, lb./sq.ft.	1.3647	D/S, lb./sq.ft.	3.0392

Effect of airbrakes on rudder of RE–1 airplane 0° pitch and yaw V=40 f. p. s. (Ref. R. and M. 112)

B6

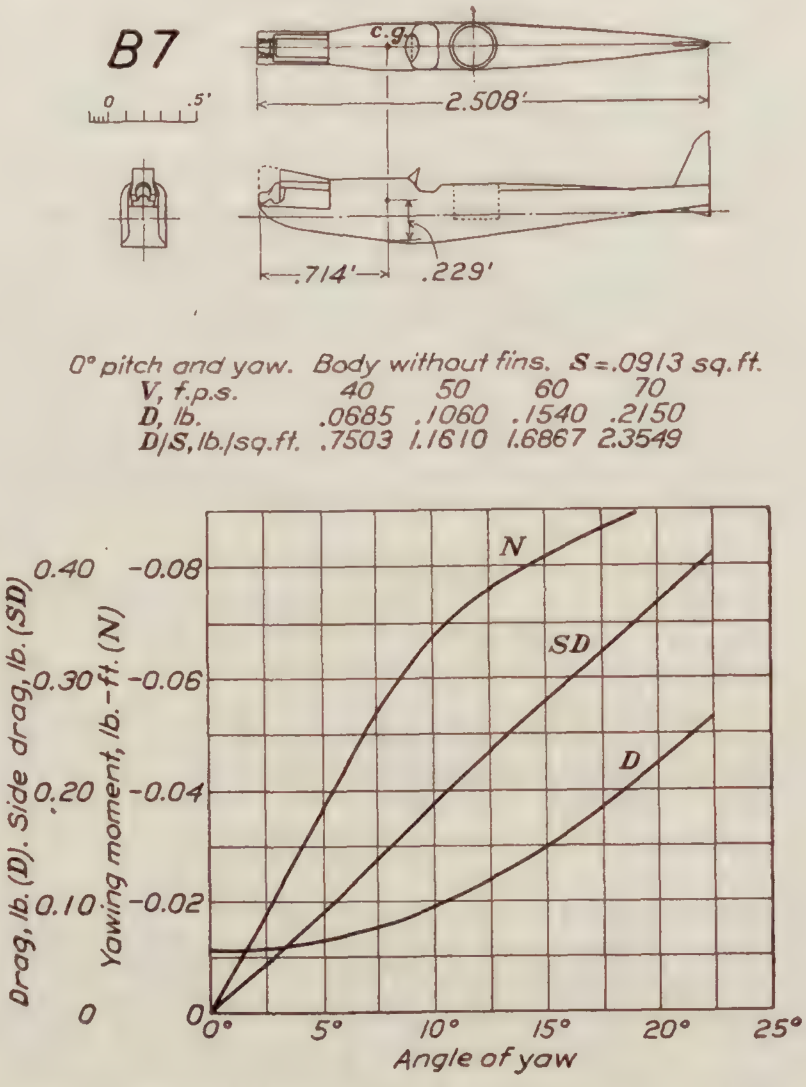


$S_f=.110$ sq. ft. (fin) $S_r=.160$ sq. ft. (rudder) $S=.0928$ sq. ft.
0° pitch and yaw V, 40 f.p.s. With brakes, $S=.1578$ sq. ft.

Rudder neutral: Airbrakes closed.		Rudder neutral: Airbrakes open.		Without fin & rudder: Airbrakes closed.	
D, lb.	.0753	D, lb.	.1882	D, lb.	.0697
D/S, lb./sq.ft.	.8114	D/S, lb./sq.ft.	1.193	D/S, lb./sq.ft.	.7511

Forces and moments in yaw on RE–7 airplane fuselage fitted with airbrakes. V=40 f. p. s. (Ref. R. and M. No. 153)

B7

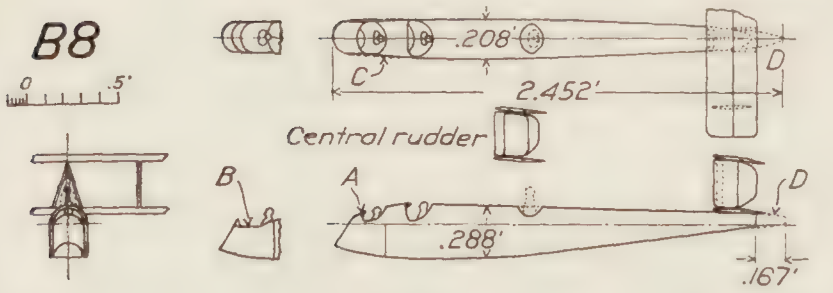


0° pitch and yaw. Body without fins. $S=.0913$ sq.ft.

V, f.p.s.	40	50	60	70
D, lb.	.0685	.1060	.1540	.2150
D/S, lb./sq.ft.	.7503	1.1610	1.6867	2.3549

Forces and moments in yaw on RE–8 airplane fuselage with fins shown. V=40 f. p. s. (Ref. R. and M. No. 201)

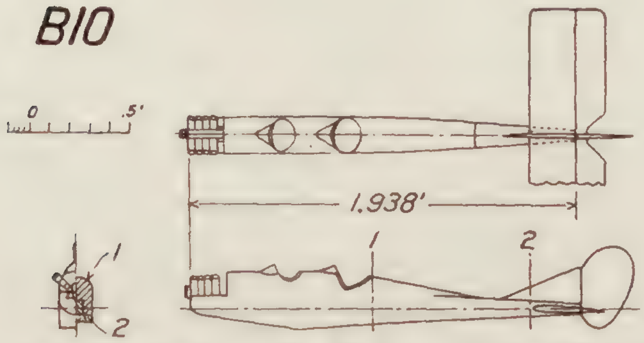
B8



0° pitch and yaw V = 40 f.p.s. S = .0560 sq. ft.
Model as shown "A" - - - - - - - - D = .0730 lb., D/S = 1.3036 lb./sq. ft.
1, Body without stabilizers - - D = .0294 lb., D/S = .5250 lb./sq. ft.
2, With cockpit "B" - - - - - - - - D = .0314 lb., D/S = .5607 lb./sq. ft.
3, (1) With fairing "C" - - - - - D = .0263 lb., D/S = .4696 lb./sq. ft.
4, (1) " man in open cockpit D = .0394 lb., D/S = .7036 lb./sq. ft.
5, (1) 3rd cockpit faired over D = .0296 lb., D/S = .4804 lb./sq. ft.
6, (1) With fairing "D" added - - D = .0265 lb., D/S = .4732 lb./sq. ft.
Area of fixed fin = .0667 sq. ft. Area of central rudder = .035 sq. ft.
" " outer rudders = .0425 sq. ft. Total fin area = .1442 sq. ft.

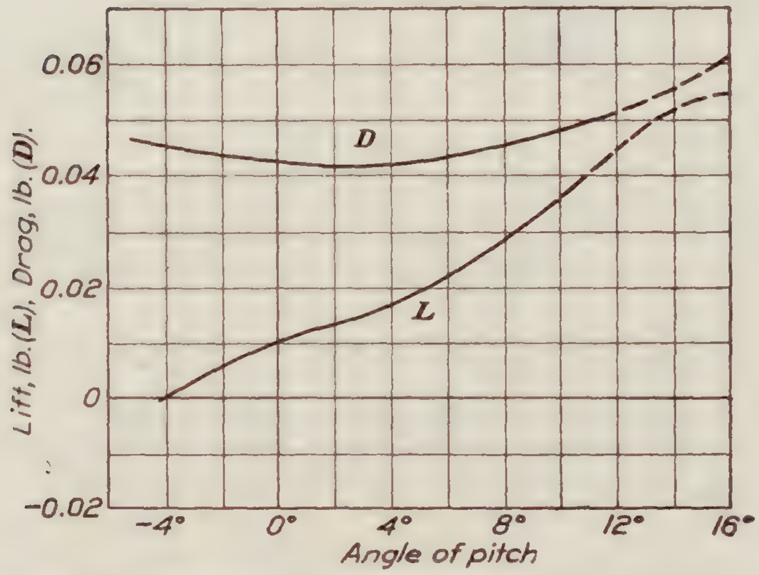
Drag on fuselage of FE–4 airplane. 0° pitch and yaw V=40 f. p. s. (Ref. R. and M. No. 221)

B10



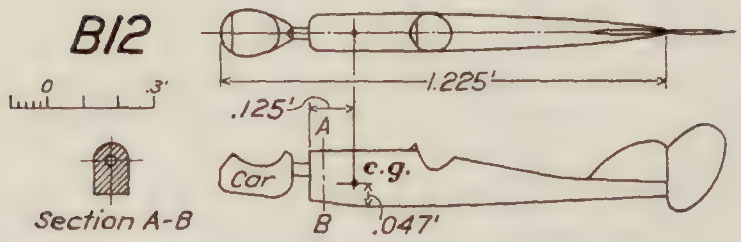
Complete model V = 40 f.p.s. S = .0520 sq. ft.

Angle of pitch	−2°	+3°	+8°	+13°
D, lb.	.0850	.0650	.0710	.1120
D/S, lb./sq. ft.	1.6346	1.2500	1.3654	2.1538



Lift and drag on fuselage only of BE–2c airplane. (Ref. R. and M. No. 254)

B12

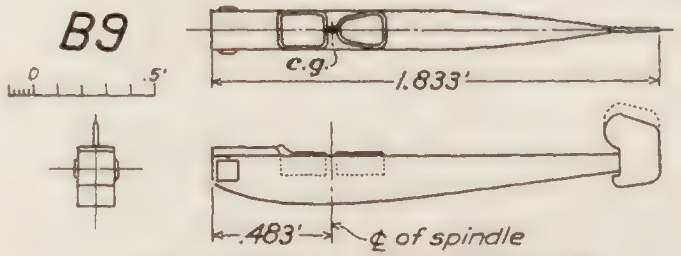


0° pitch and yaw V = 40 f.p.s. S = .0935 sq. ft.

Without car	D, lb.	.0275	With car: D, lb.	.0352
	D/S, lb./sq. ft.	.2941	D/S, lb./sq. ft.	.3765

Drag with faired car on body of BE–9 airplane. (Ref. R. and M. No. 202)

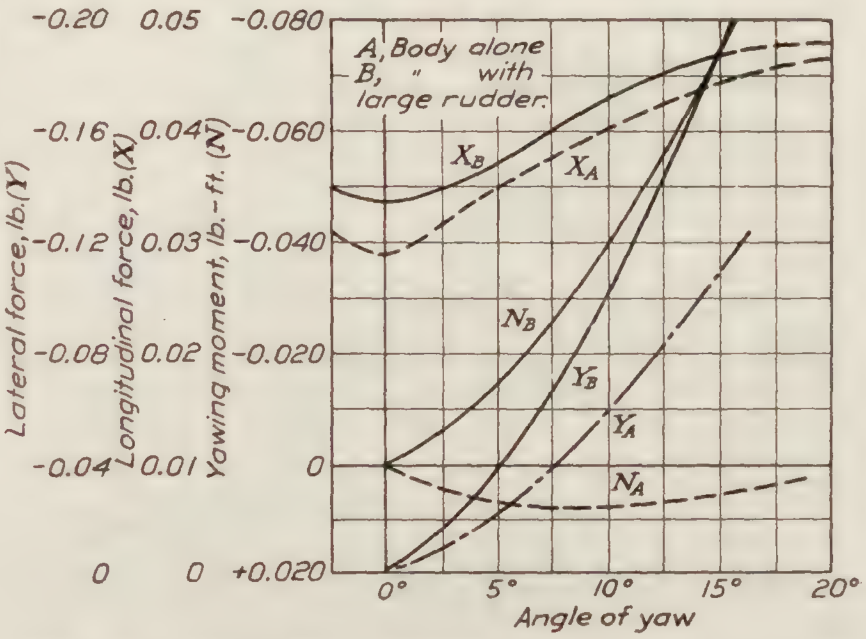
B9



Area of large rudder = .0598 sq. ft.
" " small " = .0458 " ".

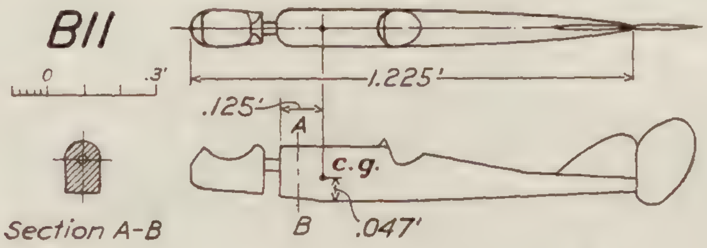
0° pitch and yaw S = .0390 sq. ft.

With large rudder		Body alone	
V, f.p.s.	40	V, f.p.s.	40
D, lb.	.0332	D, lb.	.0287
D/S, lb./sq. ft.	.8513	D/S, lb./sq. ft.	.7359



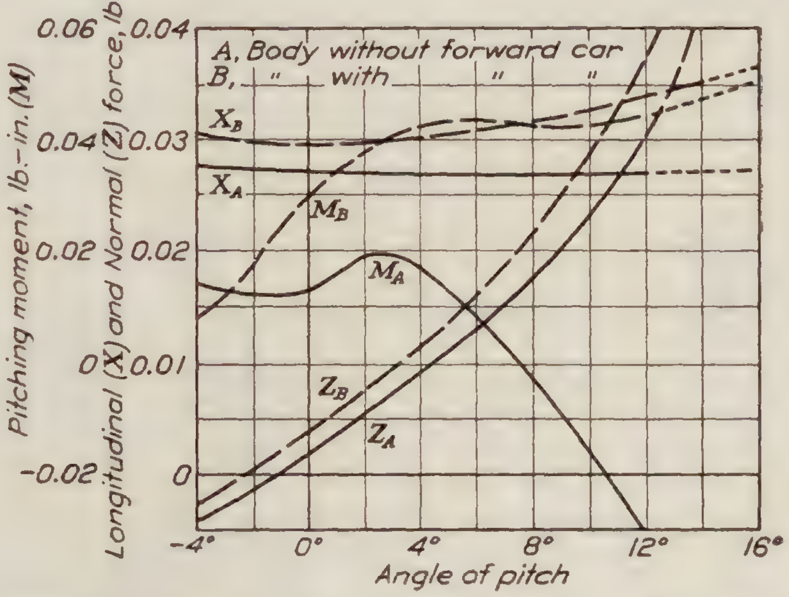
Forces and moments in yaw on fuselage of Avro seaplane. V=40 f. p. s. (Ref. R. and M. No. 156)

B11



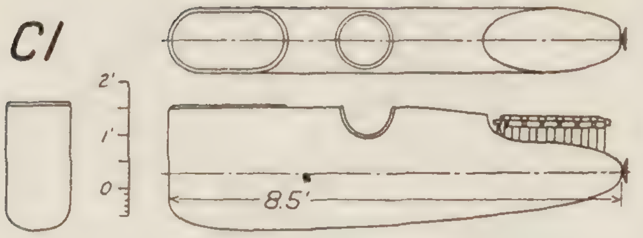
0° pitch and yaw V = 40 f.p.s. S = .0935 sq. ft.

Without forward car		With forward car	
D, lb.	.0275	D, lb.	.0296
D/S, lb./sq. ft.	.2941	D/S, lb./sq. ft.	.3166



Forces and moments in pitch with unfaired car on fuselage of BE–9 airplane. V=40 f. p. s. (Ref. R. and M. No. 202)

C1

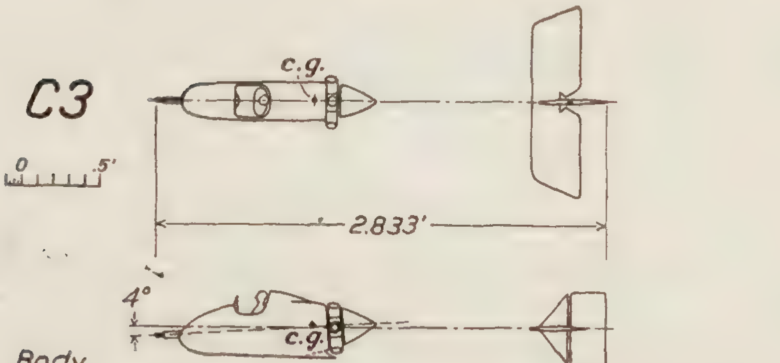


0° pitch and yaw $S=2.60$ sq. ft.

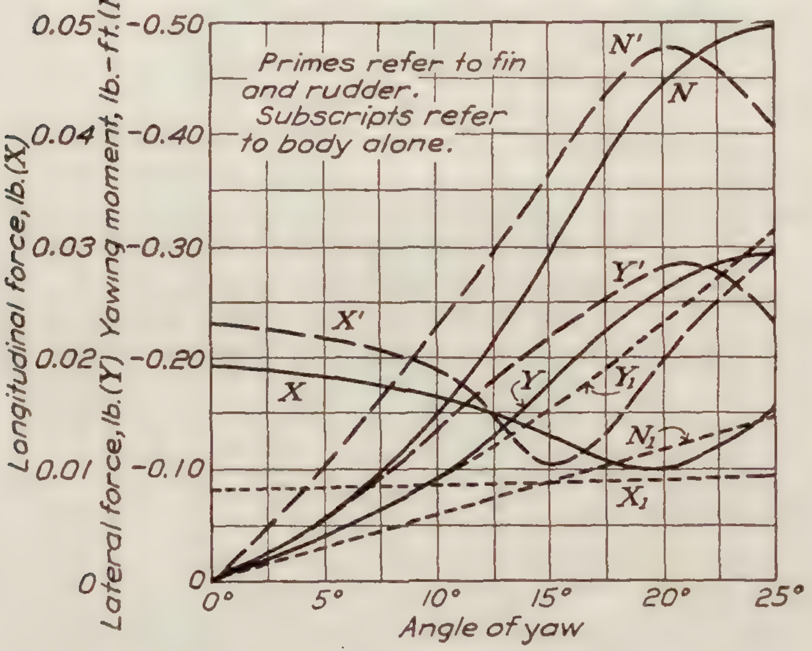
V, f. p. s.	58.7	88.0	117.3	146.6
D, lb.	3.7800	8.3500	14.7000	22.7000
D/S, lb./sq. ft.	1.4538	3.2115	5.6538	8.7308

Drag on nacelle of Davis-gun seaplane. (Ref. W. T. R. No. 67)

C3

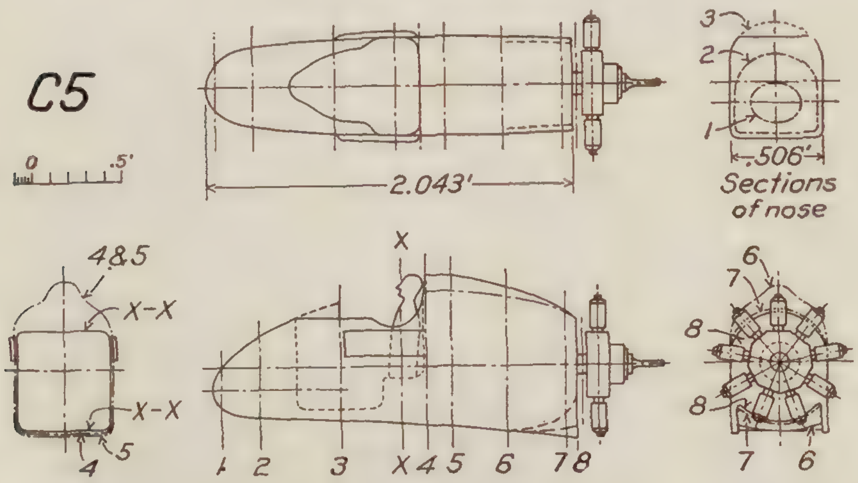


Body alone 0° pitch and yaw $S=.0910$ sq. ft. (approx.)
$V=40$ f. p. s. $D=.0848$ lb $D/S=.9319$ lb./sq. ft.



Forces and moments of fin and rudder. FE-8 airplane nacelle. $V=40$ f. p. s. (Ref. R. and M. No. 156)

C5

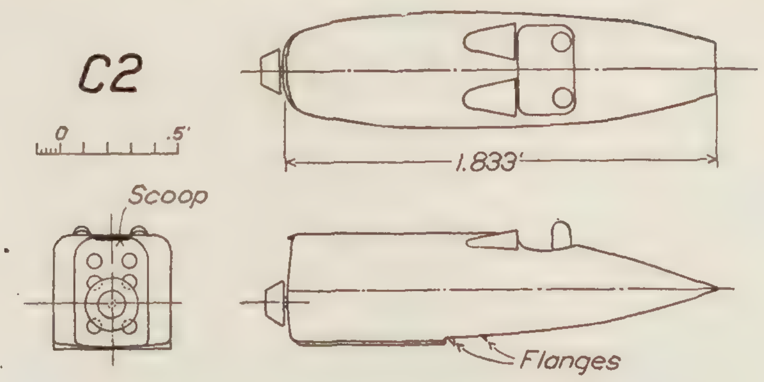


0° pitch and yaw $S=.4180$ sq. ft.

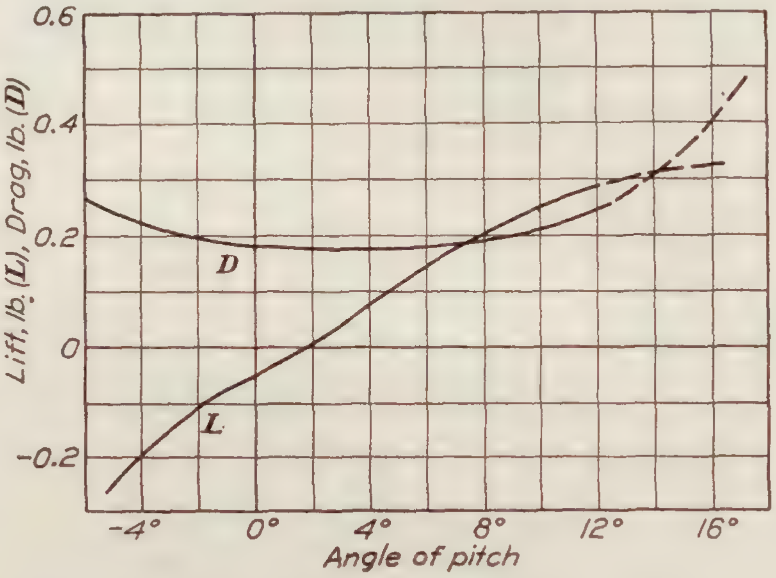
V, f. p. s.	30	40	50	60
D, lb.	.1250	.2180	.3410	.4900
D/S, lb./sq. ft.	.2990	.5220	.8150	1.1700

Drag on nacelle of FE-8 airplane. (Ref. R. and M. No. 305)

C2

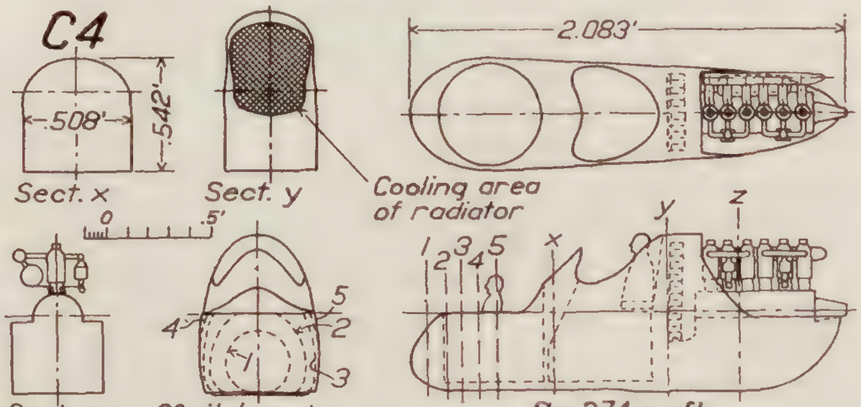


0° pitch and yaw $S=.258$ sq. ft.
$V=58.7$ f. p. s. $D=.1883$ lb $D/S=.7298$ lb./sq. ft.



Lift and drag on nacelle of Richardson seaplane. $V=58.7$ f. p. s. (Ref. W. T. R. No. 54)

C4

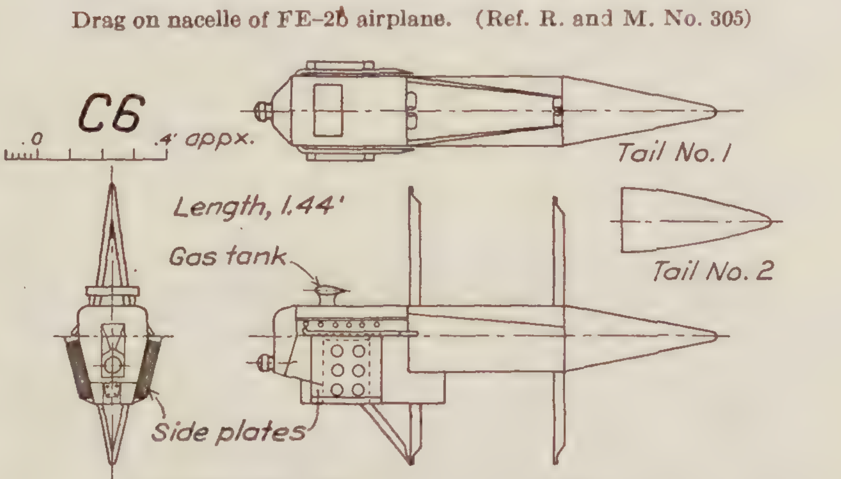


0° pitch and yaw $S=.374$ sq. ft.

V, f. p. s.	30	40	50	60
D, lb.	.1520	.2710	.4250	.6060
D/S, lb./sq. ft.	.4060	.7240	1.1360	1.6200

Drag on nacelle of FE-2b airplane. (Ref. R. and M. No. 305)

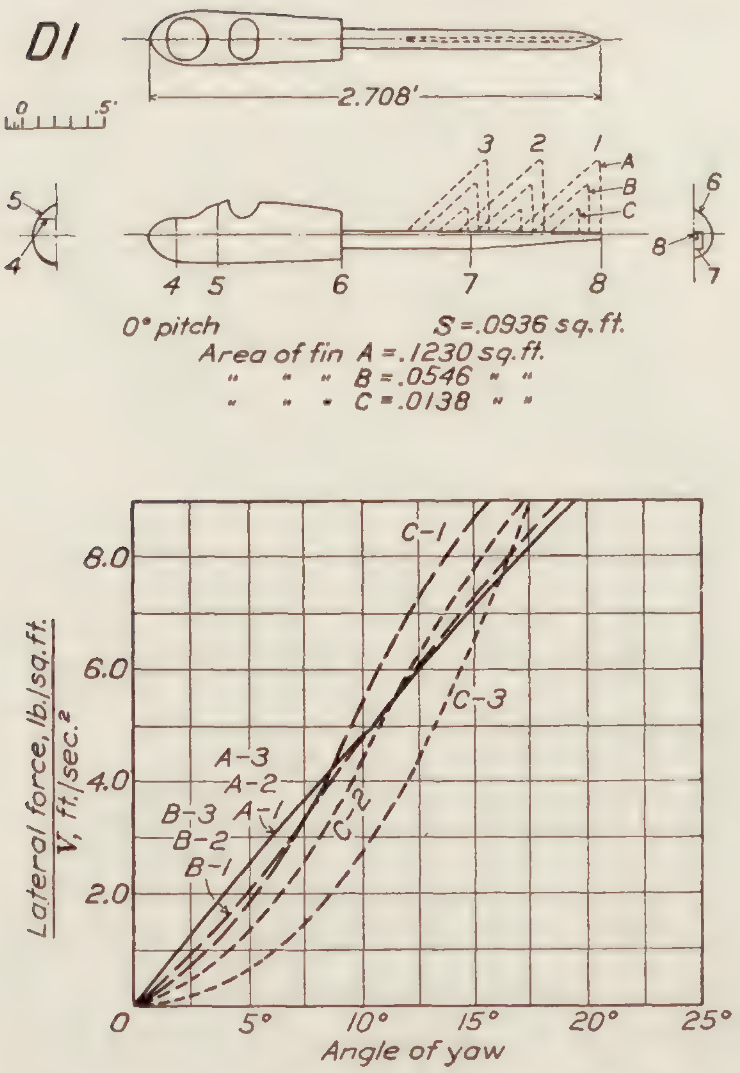
C6



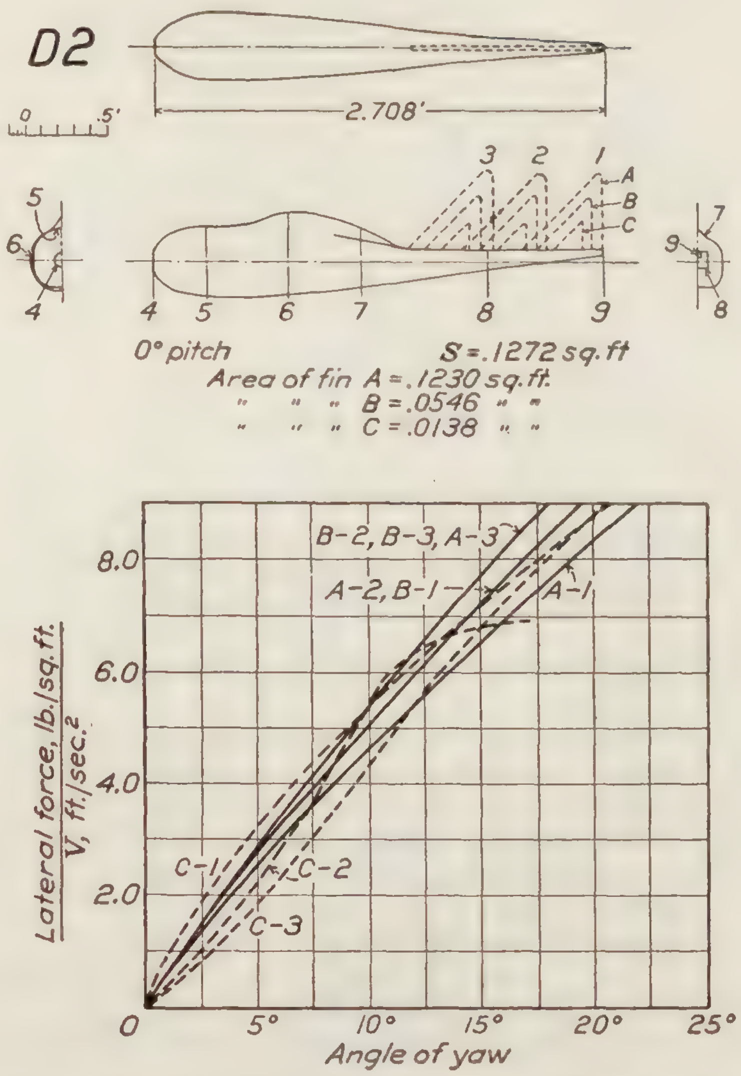
0° pitch and yaw $V=40.0$ f. p. s.

No. 1 tail with, radiators,	$D=.1120$ lb.,	without,	$D=.0865$ lb.
No. 2 " " " ,	$D=.1151$ lb.,	"	$D=.0874$ lb.
Without tail, " "	$D=.1210$ lb.,	"	$D=.1088$ lb.
Drag due to, side plates,	$D=.0103$ lb.,	gas tank,	$D=.0072$ lb.

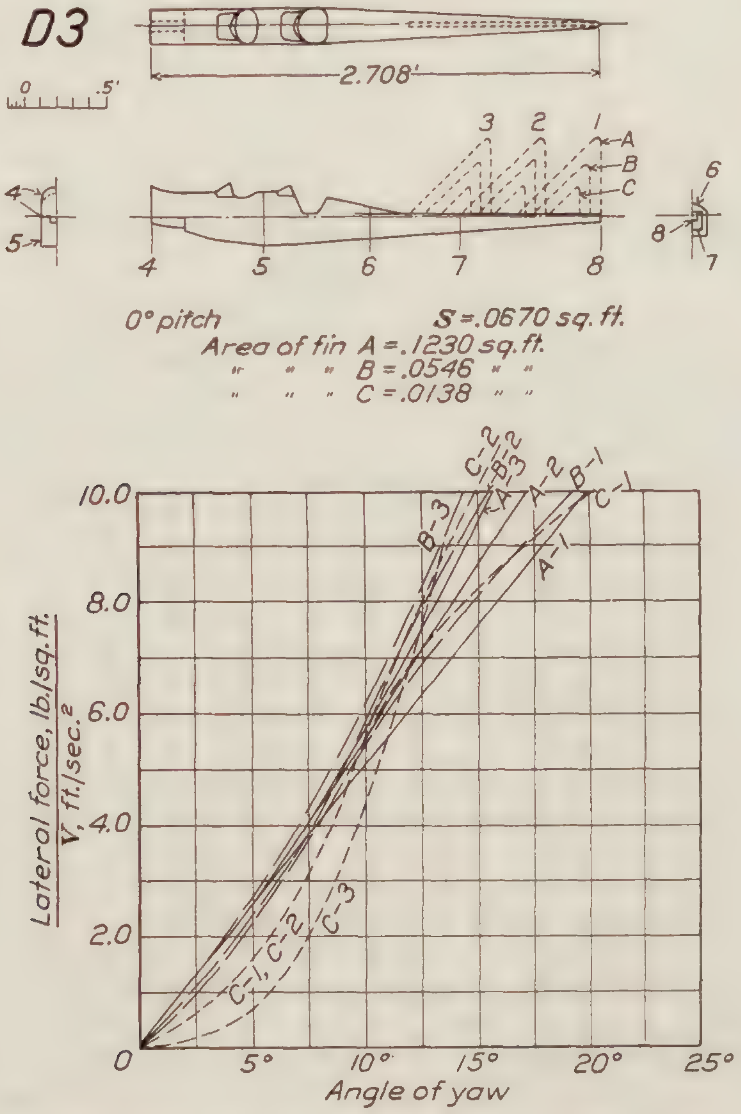
Drag on nacelle of Handley Page airplane. (Ref. R. and M. No. 251)



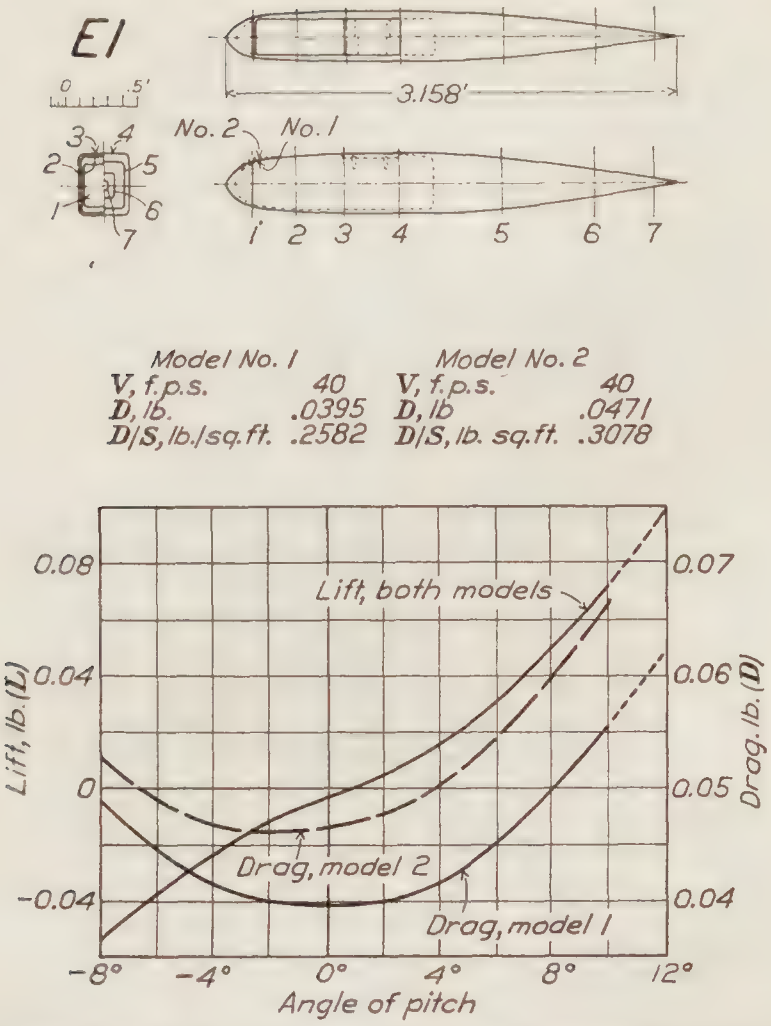
Lateral force on fin only of FE type fuselage. (Ref. R. and M. No. 201)



Lateral force on fin only of SE type fuselage. (Ref. R. and M. No. 201)

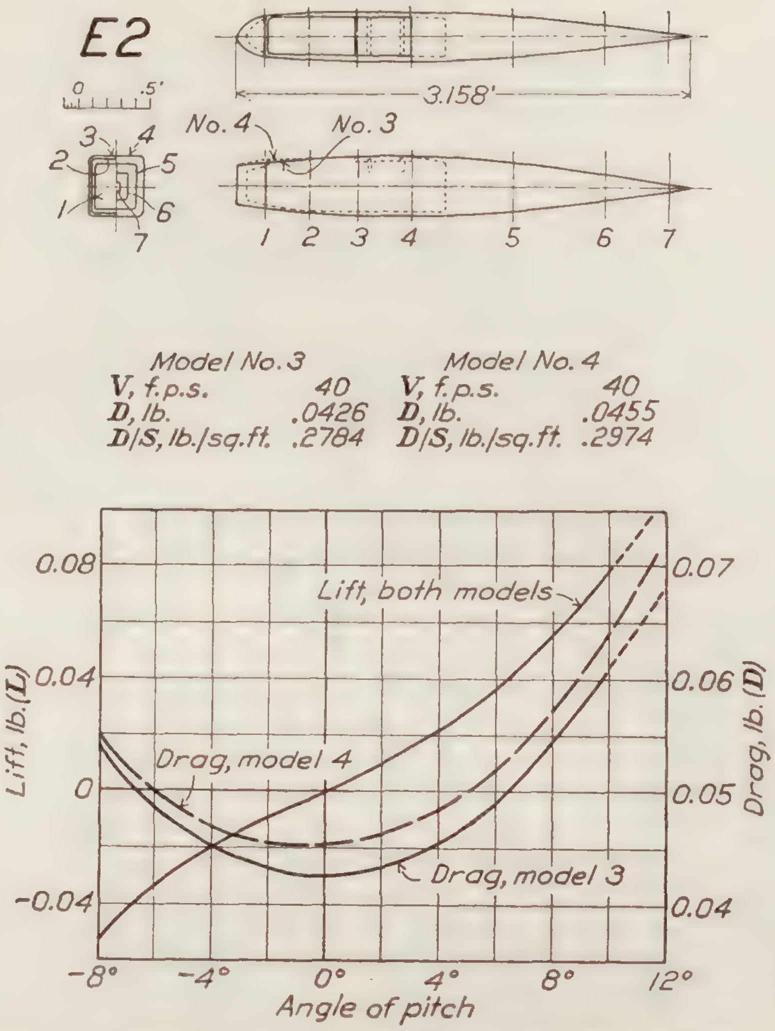


Lateral force on fin only of RE or Be type fuselage. (Ref. R. and M. No. 201)



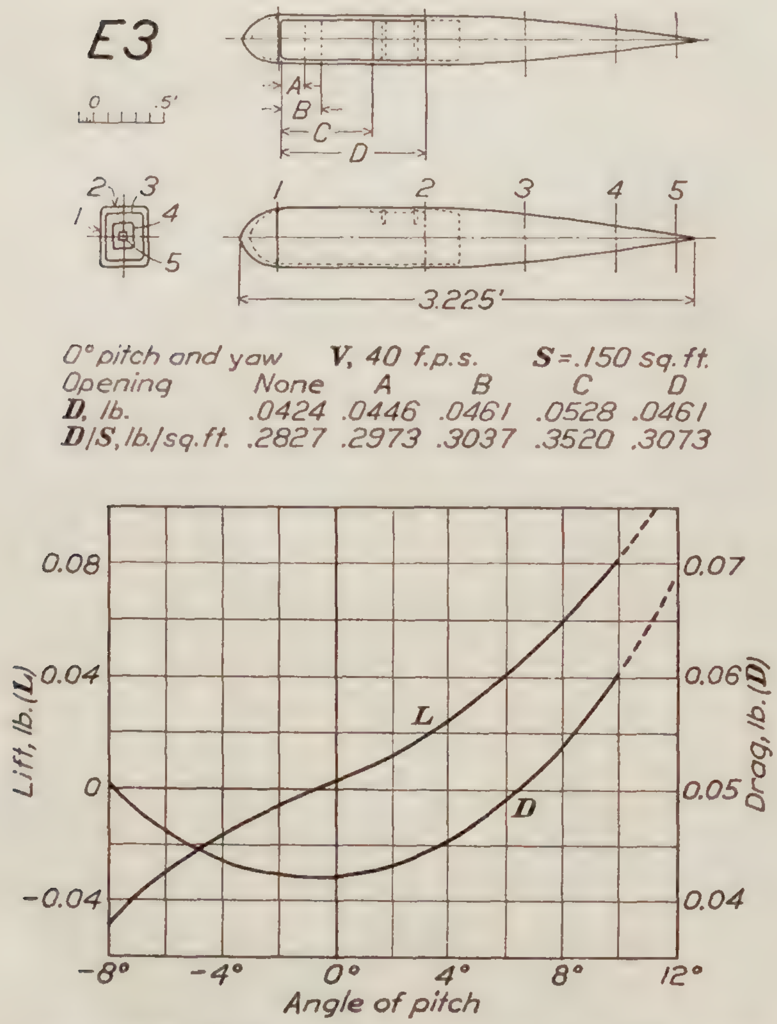
Model No. 1		Model No. 2	
V, f.p.s.	40	V, f.p.s.	40
D, lb.	.0395	D, lb	.0471
D/S, lb./sq.ft.	.2582	D/S, lb. sq.ft.	.3078

Lift and drag on H. M. A. "Epsilon" airship car, models Nos. 1 and 2



Model No. 3		Model No. 4	
V, f.p.s.	40	V, f.p.s.	40
D, lb.	.0426	D, lb.	.0455
D/S, lb./sq.ft.	.2784	D/S, lb./sq.ft.	.2974

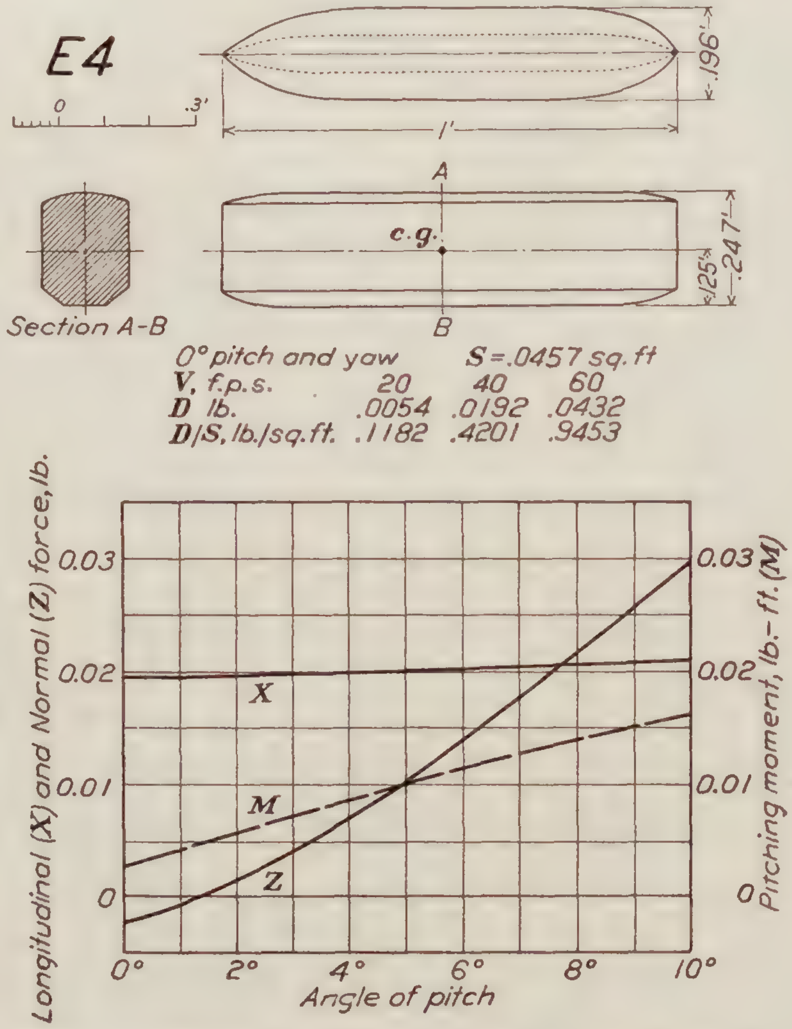
Lift and drag on H. M. A. "Epsilon" airship car, models Nos. 3 and



0° pitch and yaw **V**, 40 f.p.s. **S**=.150 sq.ft.

Opening	None	A	B	C	D
D, lb.	.0424	.0446	.0461	.0528	.0461
D/S, lb./sq.ft.	.2827	.2973	.3037	.3520	.3073

Lift and drag on H. M. A. "Epsilon" airship car. (Ref. R. and M. No. 108)

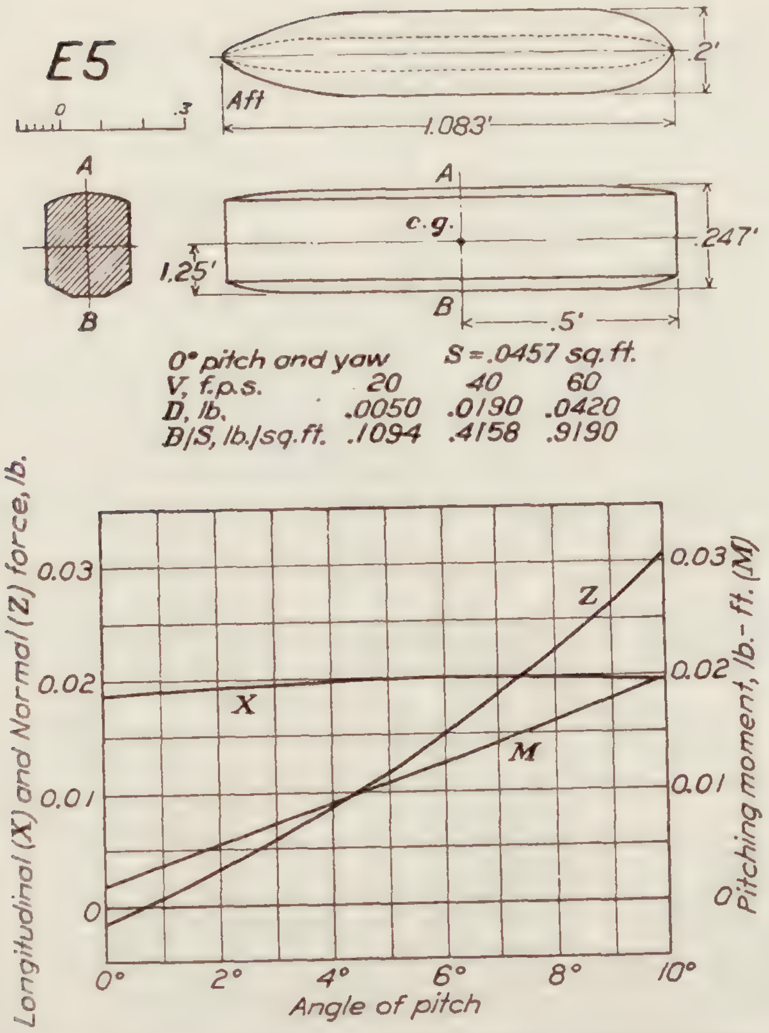


0° pitch and yaw **S**=.0457 sq. ft

V, f.p.s.	20	40	60
D lb.	.0054	.0192	.0432
D/S, lb./sq.ft.	.1182	.4201	.9453

Forces and moments in pitch on airship car "A." (Ref. R. an d M. No. 151)

E5

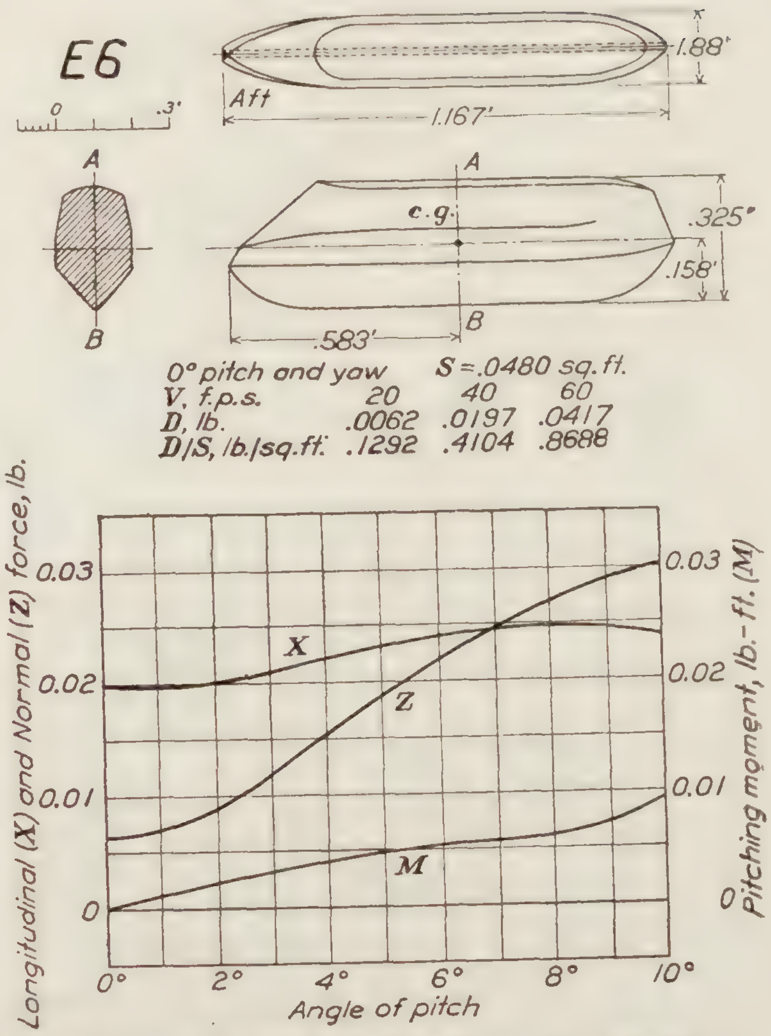


0° pitch and yaw S = .0457 sq. ft.

V, f.p.s.	20	40	60
D, lb.	.0050	.0190	.0420
D/S, lb./sq. ft.	.1094	.4158	.9190

Forces and moments in pitch on airship car "B." (Ref. R. and M. No. 151)

E6

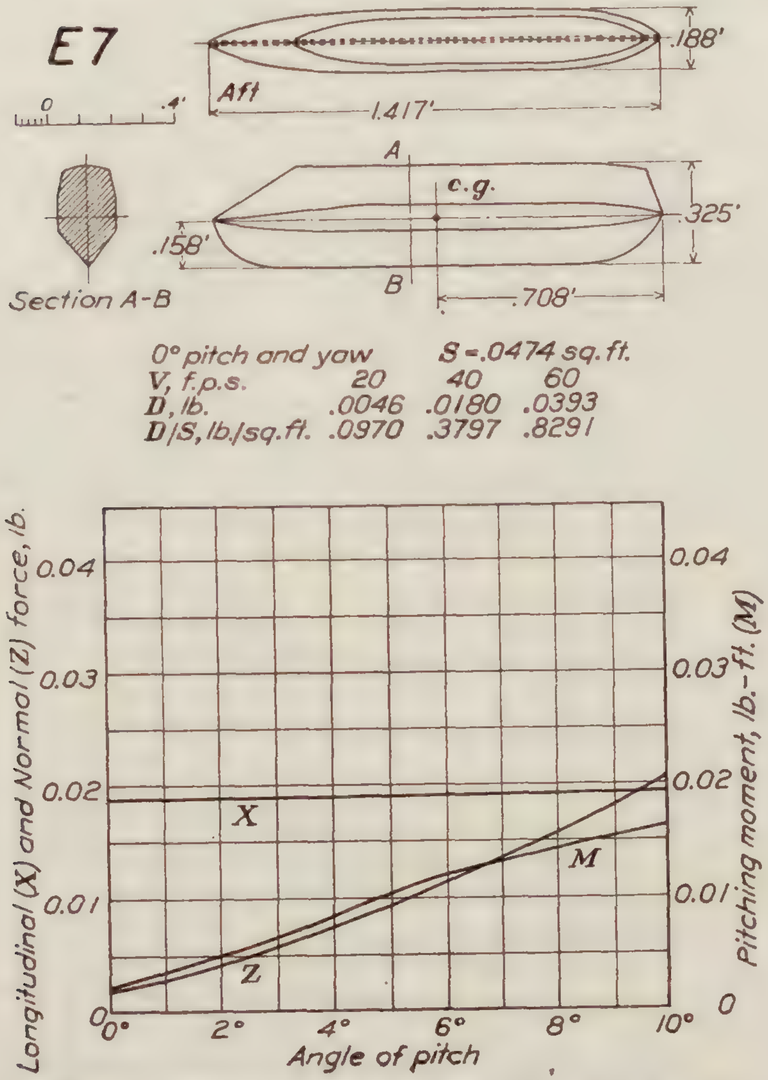


0° pitch and yaw S = .0480 sq. ft.

V, f.p.s.	20	40	60
D, lb.	.0062	.0197	.0417
D/S, lb./sq. ft.	.1292	.4104	.8688

Forces and moments in pitch on airship car "C." (Ref. R. and M. No. 151)

E7

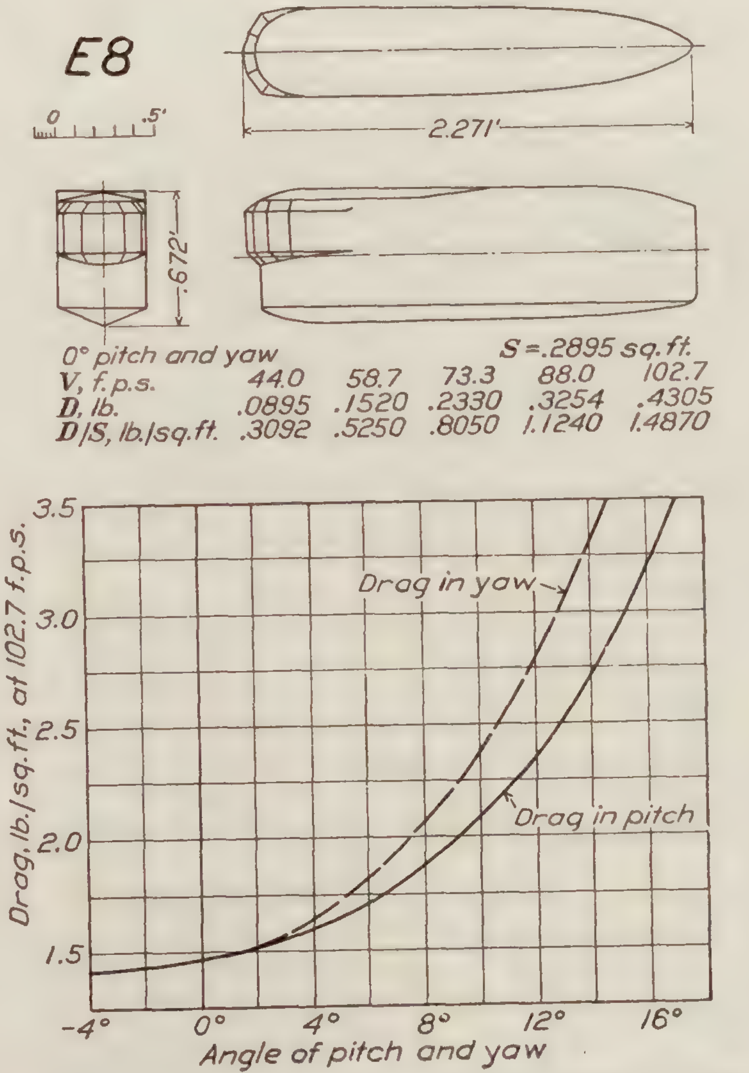


0° pitch and yaw S = .0474 sq. ft.

V, f.p.s.	20	40	60
D, lb.	.0046	.0180	.0393
D/S, lb./sq. ft.	.0970	.3797	.8291

Forces and moments in pitch on airship car "D." Ref. R. and M. No. 151)

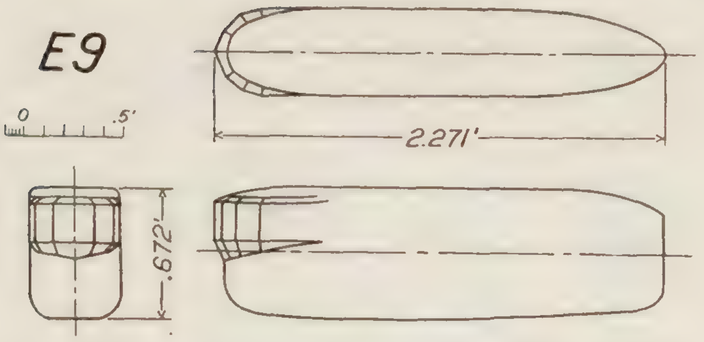
E8



0° pitch and yaw S = .2895 sq. ft.

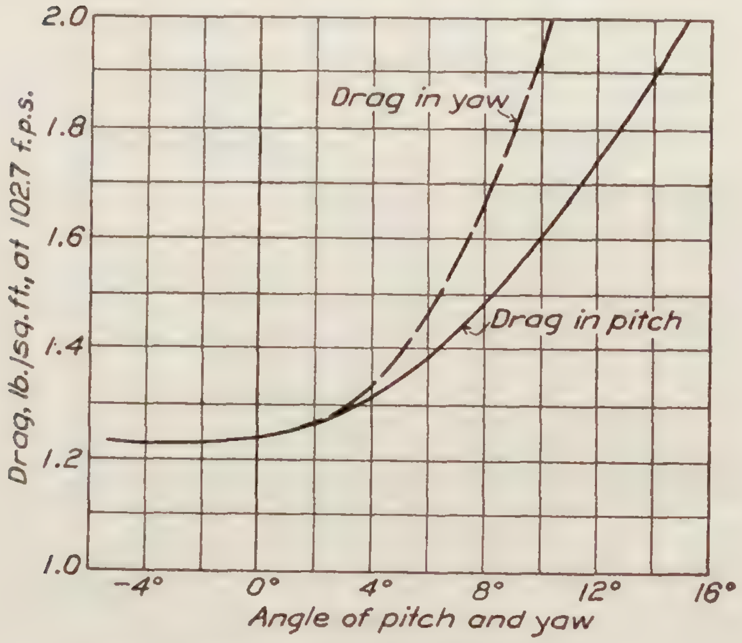
V, f.p.s.	44.0	58.7	73.3	88.0	102.7
D, lb.	.0895	.1520	.2330	.3254	.4305
D/S, lb./sq. ft.	.3092	.5250	.8050	1.1240	1.4870

Drag on closed airship car, model No. 326. (Ref. W. T. R. No. 145)

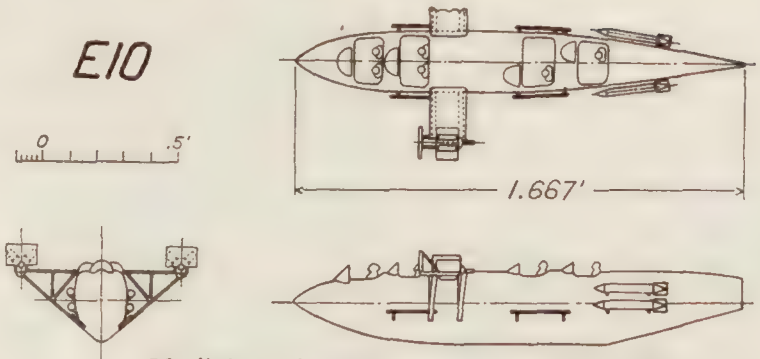


0° pitch and yaw S=.3034 sq.ft.

V, f.p.s.	44.0	58.7	73.3	88.0	102.7
D, lb.	.0783	.1314	.2005	.2816	.3705
D/S, lb./sq.ft.	.2580	.4330	.6610	.9230	1.2210



Drag on closed airship car, model No. 325. (Ref. W. T. R. No. 145)

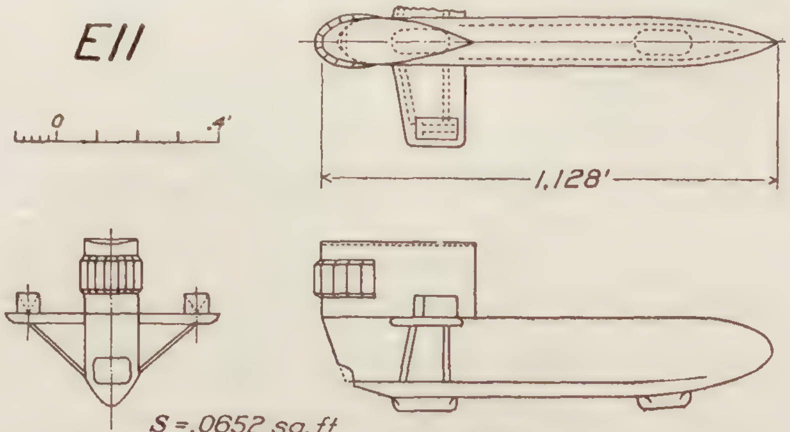


0° pitch and yaw S=.0630 sq.ft.

V, f.p.s.	29.3	44.0	58.7	73.3	88.0
D, lb.	.0468	.1040	.1835	.2834	.3996
D/S, lb./sq.ft.	.7429	1.6508	1.9127	4.4984	6.3429

Values for model as shown with bombs and appendages

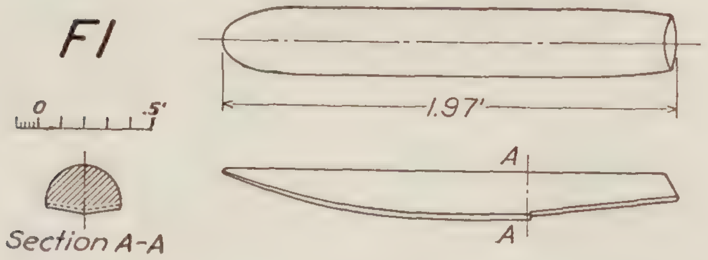
Drag on "C" class car. (Ref. W. T. R. No. 140)



S=.0652 sq.ft.

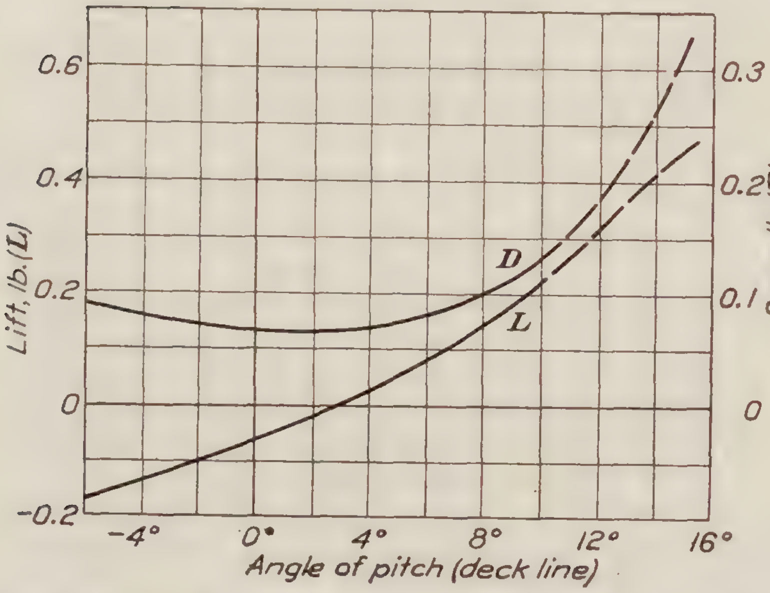
V, f.p.s.	29.3	44.0	58.7	73.3	88.0
D, lb.	.0300	.0636	.1096	.1665	.2313
D/S, lb./sq.ft.	.4601	.9755	1.6810	2.5537	3.5475

Drag on "G" class car. (Ref. W. T. R. No. 140)

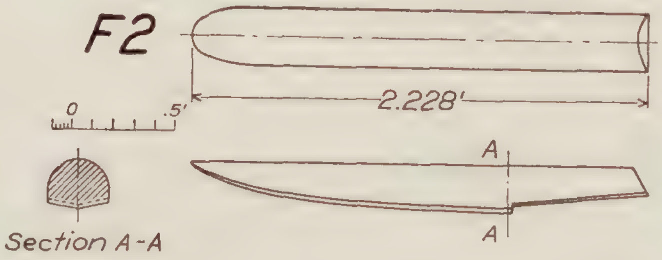


0° pitch and yaw S=.0751 sq.ft.

V, f.p.s.	44.0	58.7	73.3	88.0
D, lb.	.0366	.0627	.0963	.1390
D/S, lb./sq.ft.	.4874	.8349	1.2823	1.8509

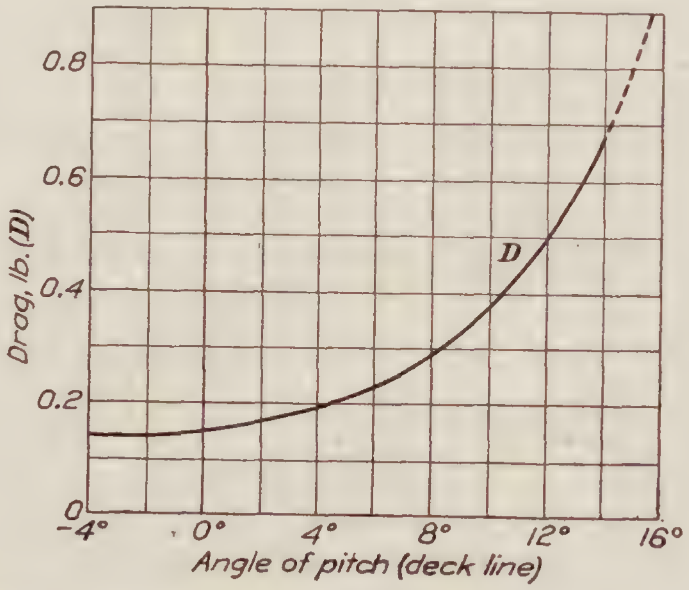


Lift and drag on Speed Scout seaplane float. $V=58.7$ f. p. s. (Ref. W. T. R. No. 18)



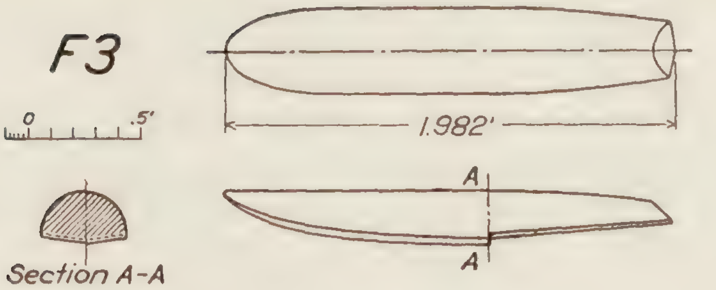
0° pitch and yaw S=.0554 sq.ft.

V, f.p.s.	44.0	58.7	73.3	88.0
D, lb.	.0394	.0681	.1063	.1495
D/S, lb./sq.ft.	.7110	1.2270	1.9180	2.6986

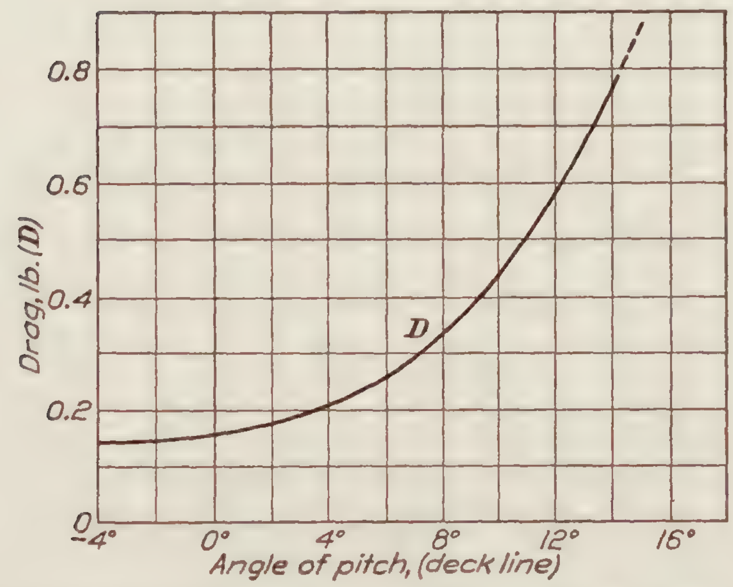


Drag on Speed Scout seaplane float. $V=88$ f. p. s. (Ref. W. T R. No. 147)

F3

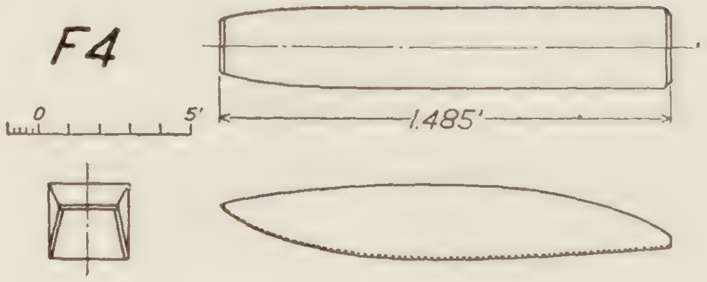


0° pitch and yaw	S = .0751 sq. ft.			
V, f.p.s.	44.0	58.7	73.3	88.0
D, lb.	.0423	.0720	.1129	.1613
D/S, lb./sq. ft.	.5632	.9587	1.5033	2.1478

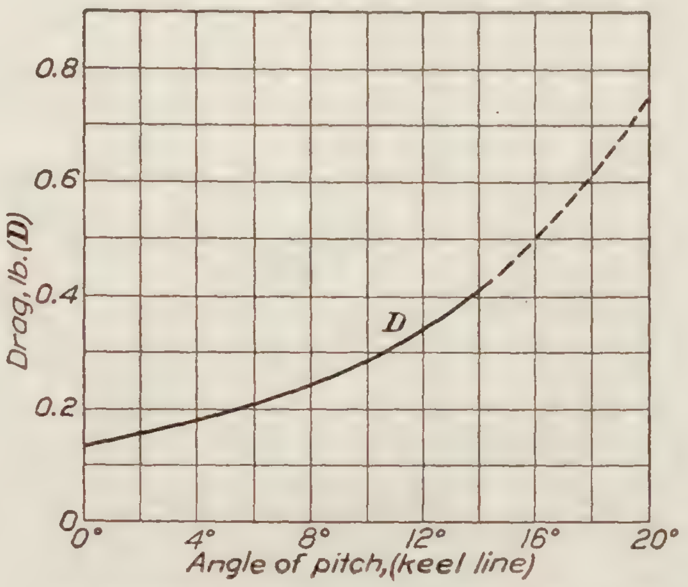


Drag on N-9 seaplane float. V=88 f. p. s. (Ref. W. T. R. No. 147)

F4

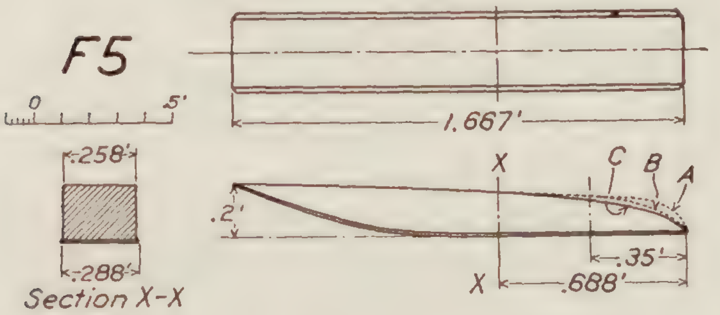


0° pitch and yaw	S = .0729 sq. ft.			
V, f.p.s.	44.0	58.7	73.3	88.0
D, lb.	.0339	.0596	.0923	.1318
D/S, lb./sq. ft.	.4650	.8176	1.2661	1.8080

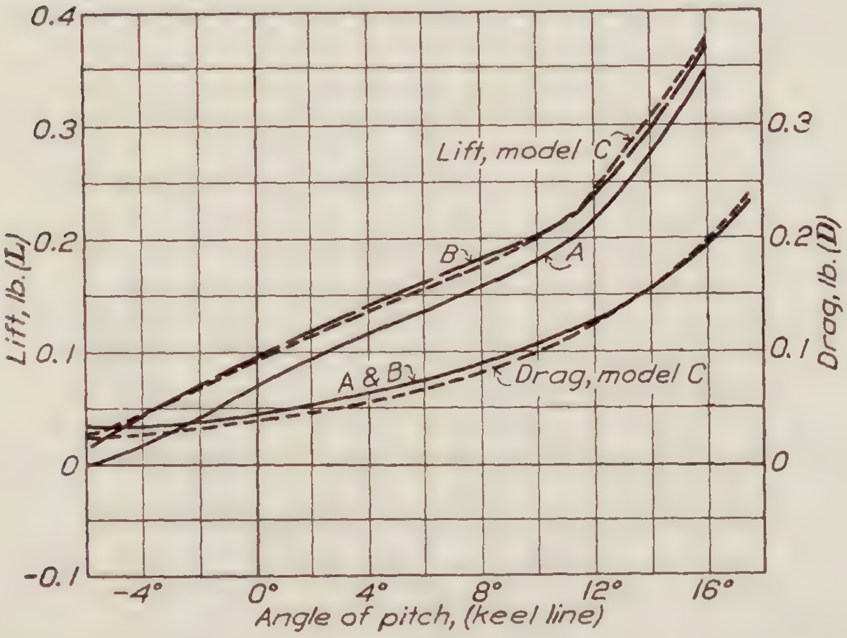


Drag on Sopwith seaplane float. V=88 f. p. s. (Ref. W. T. R. No. 147)

F5

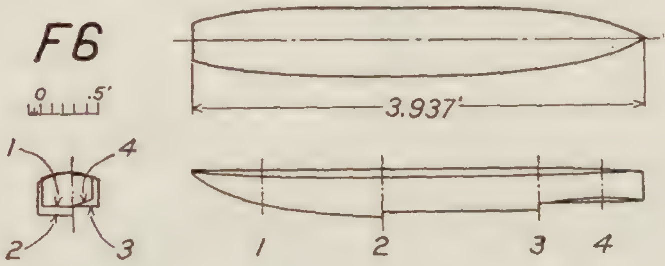


0° pitch and yaw	V = 40 f.p.s.	S = .0456 sq. ft.	
Model	A	B	C
D, lb.	.0443	.0458	.0406
D/S, lb./sq. ft.	.9715	1.0044	.8904

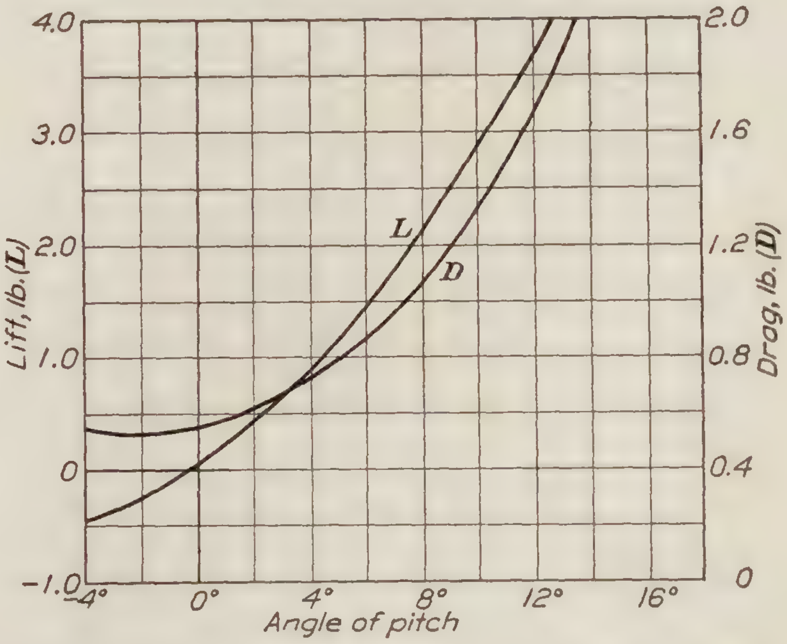


Lift and drag on seaplane float. V=58.7 f. p. s. (R. and M. No. 199)

F6

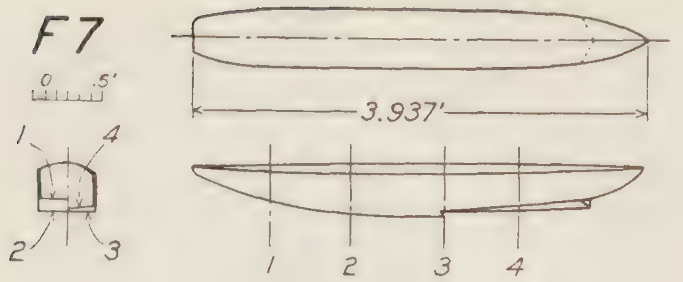


0° pitch and yaw	S = .2326 sq. ft.
V, f.p.s.	98.6
D, lb.	.5560
D/S, lb./sq. ft.	2.39

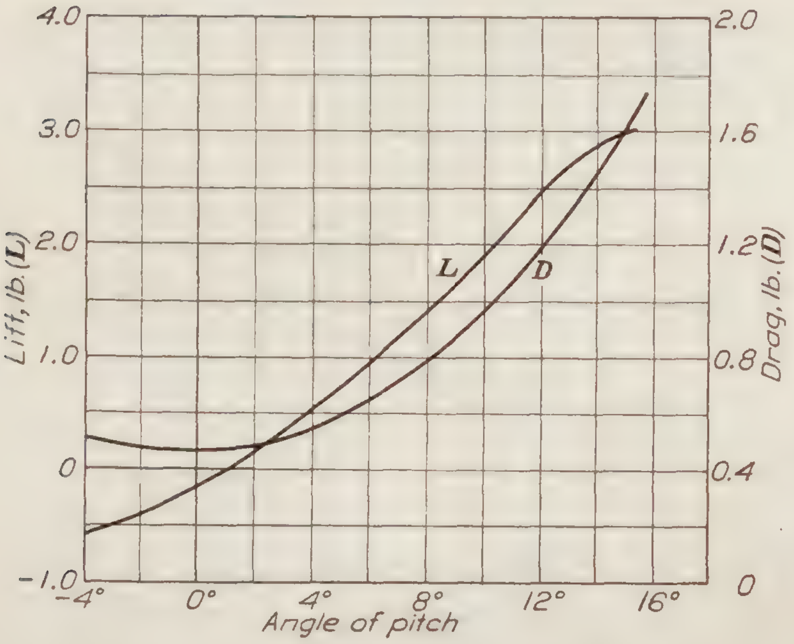


Lift and drag on Göttingen No. 1 float. V=98.6 f. p. s. (Ref. Göttingen 1921)

F7

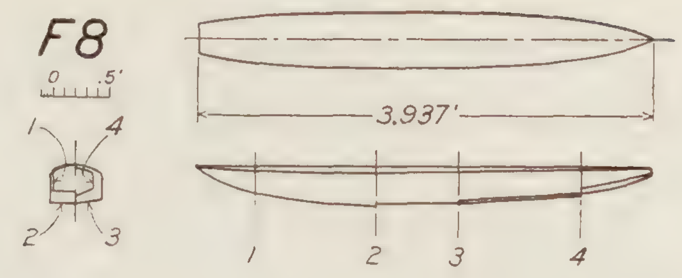


0° pitch and yaw	S = .2160 sq. ft.
V, f.p.s.	98.6
D, lb.	0.456
D/S, lb./sq.ft.	2.111

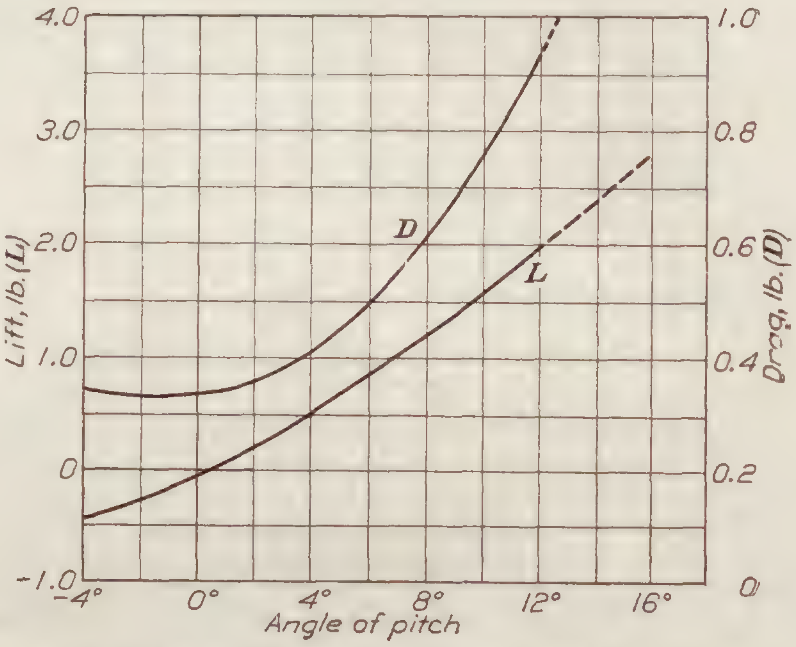


Lift and drag on Göttingen No. 2 float. V=98.6 f. p. s. (Ref. Göttingen 1921)

F8

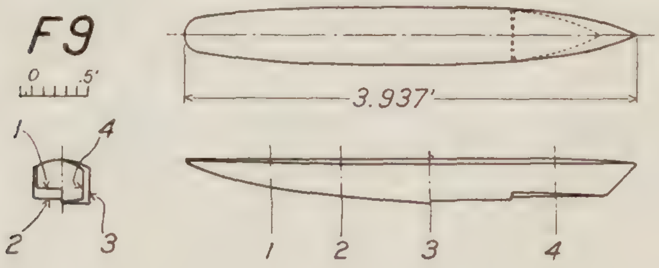


0° pitch and yaw	S = .1525 sq. ft.
V, f.p.s.	98.6
D, lb.	0.330
D/S, lb./sq.ft.	2.164

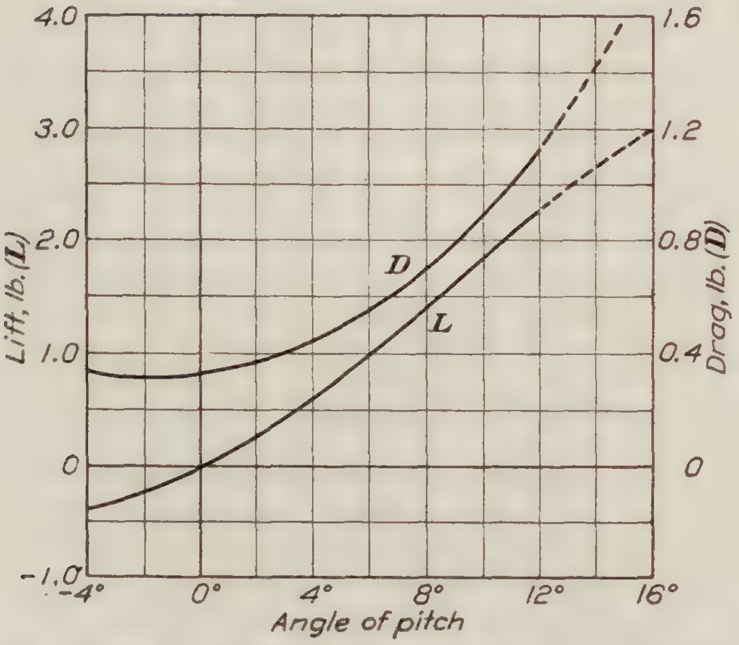


Lift and drag on Göttingen No. 3 float. V=98.6 f. p. s. (Ref. Göttingen 1921)

F9

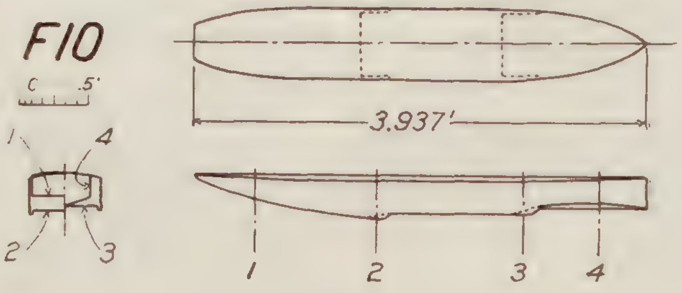


0° pitch and yaw	S = .1940 sq. ft.
V, f.p.s.	98.6
D, lb.	0.366
D/S, lb./sq.ft.	1.887

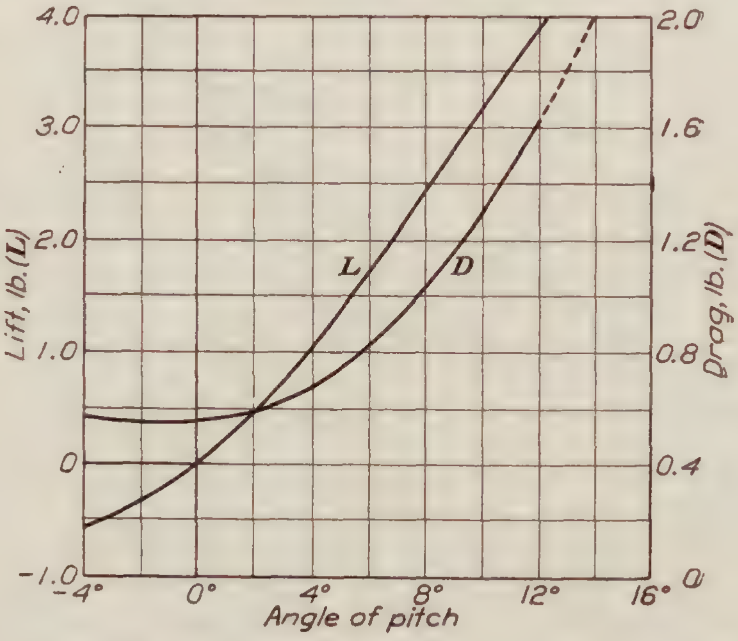


Lift and drag on Göttingen No. 4 float. V=98.6 f. p. s. (Ref. Göttingen 1921)

F10

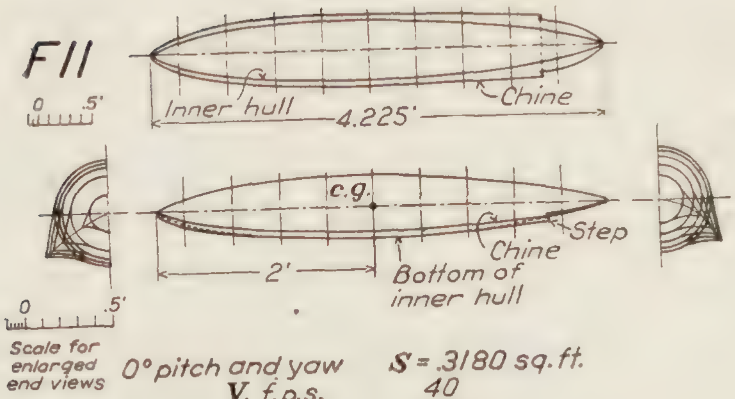


0° pitch and yaw	S = .2255 sq. ft.
V, f.p.s.	97.5
D, lb.	.5520
D/S, lb. sq.ft.	2.45

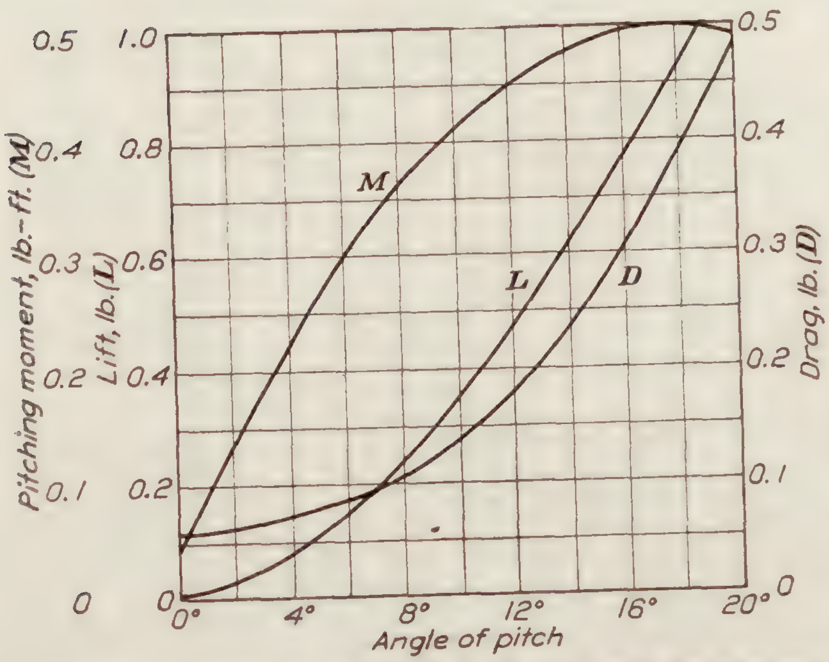


Lift and drag on Göttingen No. 5 float. V=97.5 f. p. s. (Ref. Göttingen 1921)

F11

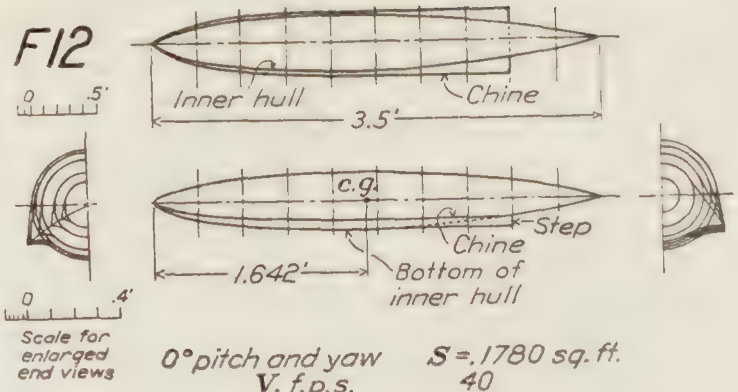


0° pitch and yaw	S = .3180 sq. ft.
V, f.p.s.	40
D, lb.	.0588
D/S, lb./sq.ft.	.1849

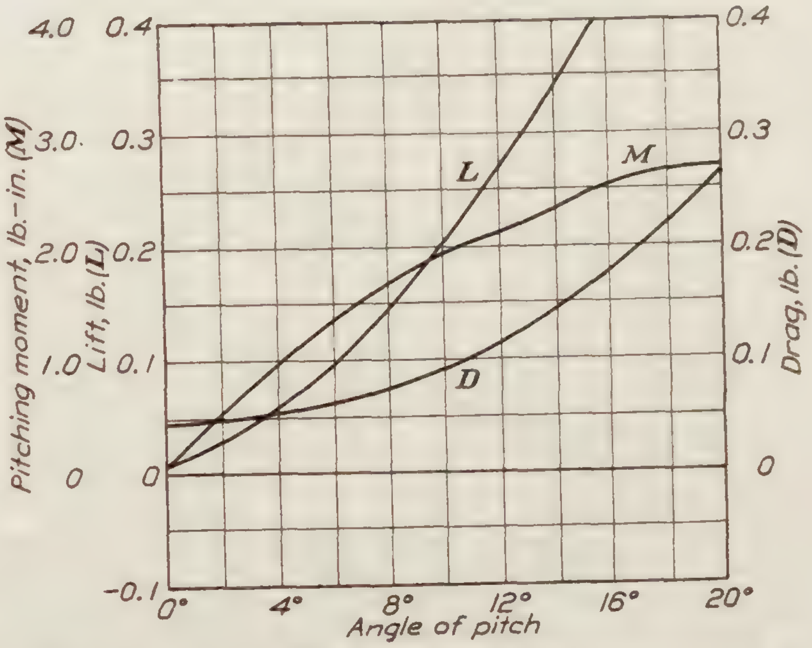


Forces and moments in pitch on an A. D. main float for short seaplanes. V=40 f. p. s. (Ref. R. and M. No. 285)

F12

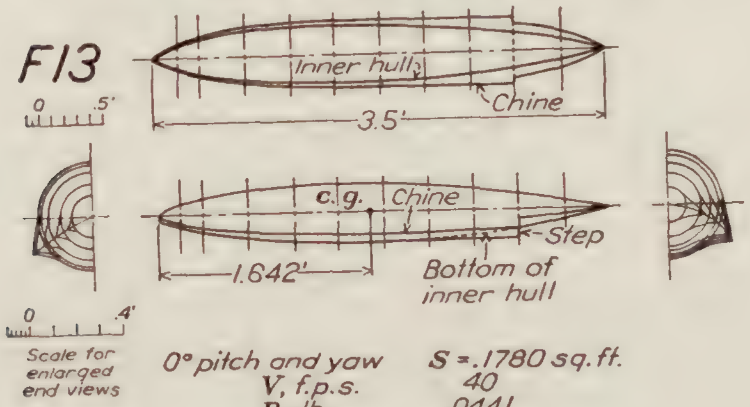


0° pitch and yaw	S = .1780 sq. ft.
V, f.p.s.	40
D, lb.	.0441
D/S, lb./sq.ft.	.2478

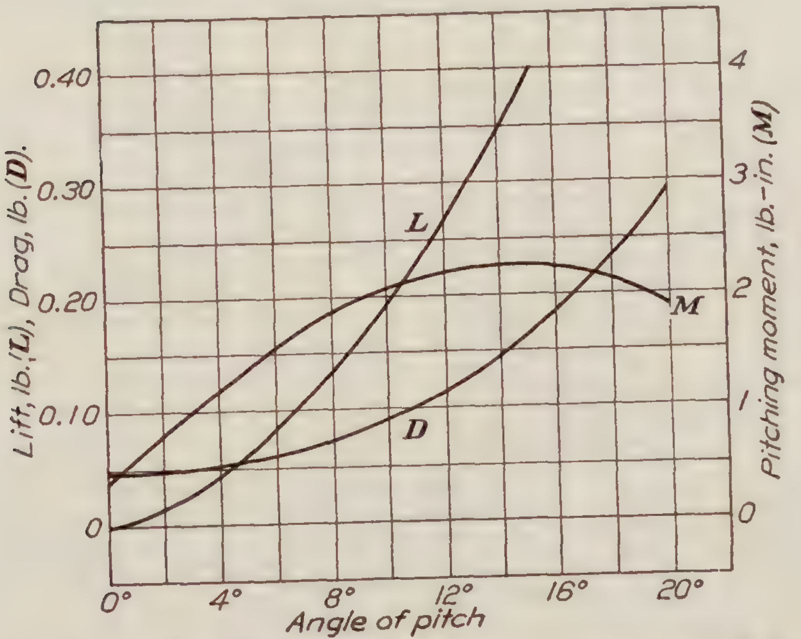


Forces and moments in pitch on a Blackburn seaplane main float No. 2. V=40 f. p. s. (Ref. R. and M. No. 285)

F13

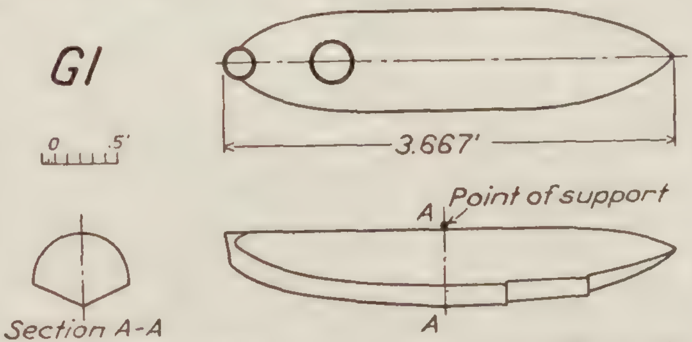


0° pitch and yaw	S = .1780 sq. ft.
V, f.p.s.	40
D, lb.	.0441
D/S, lb./sq.ft.	.2478

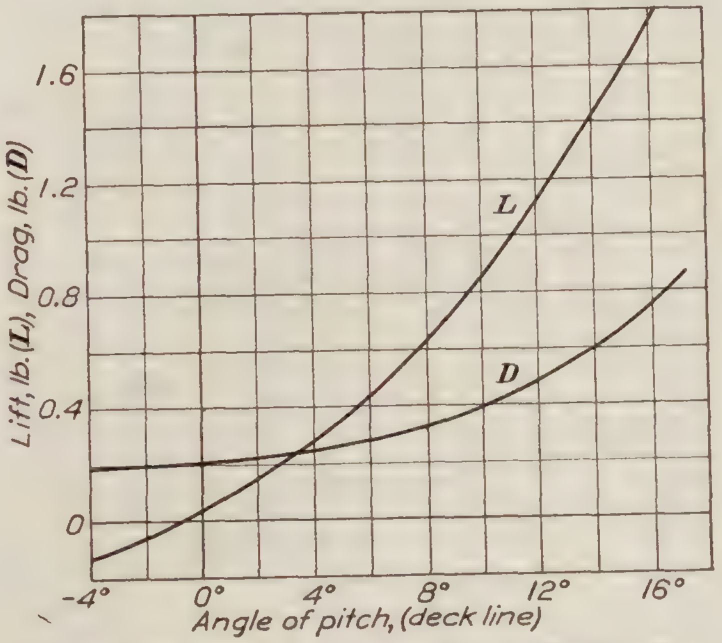


Forces and moments in pitch on a Blackburn seaplane main float No. 1. V=40 f. p. s. (Ref. R. and M. No. 285)

G1

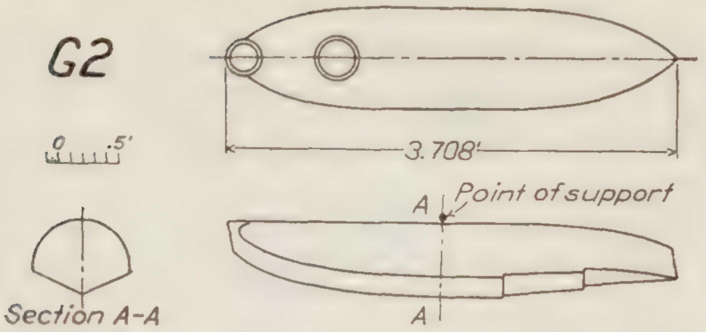


0° pitch and yaw					S = .3850 sq. ft.
V, f.p.s.	44.0	58.7	73.3	88.0	102.7
D, lb.	.1194	.2021	.3061	.4297	.5698
D/S, lb./sq.ft.	.3100	.5250	.7950	1.1160	1.4800



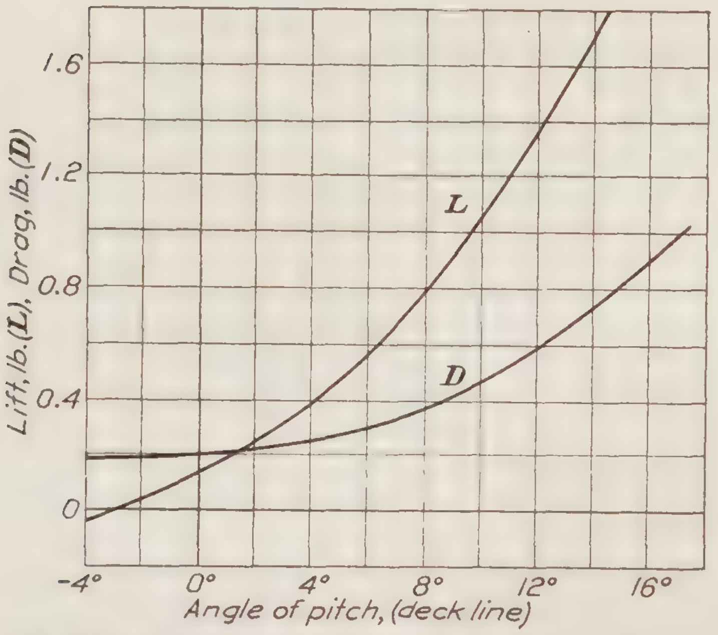
Lift and drag on NC-1 hull, stern No. 1. V=58.7 f. p. s. (Ref. W. T. R. No. 64)

G2



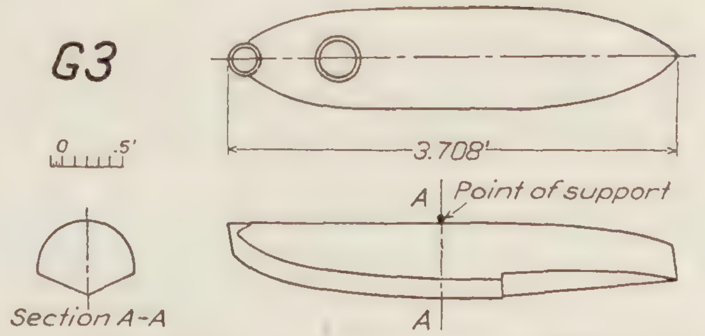
0° pitch and yaw S = .3850 sq. ft.

V, f.p.s.	44.0	58.7	73.3	88.0	102.7
D, lb.	.1232	.2098	.3099	.4397	.5852
D/S, lb./sq.ft.	.3200	.5450	.8050	1.1420	1.5200



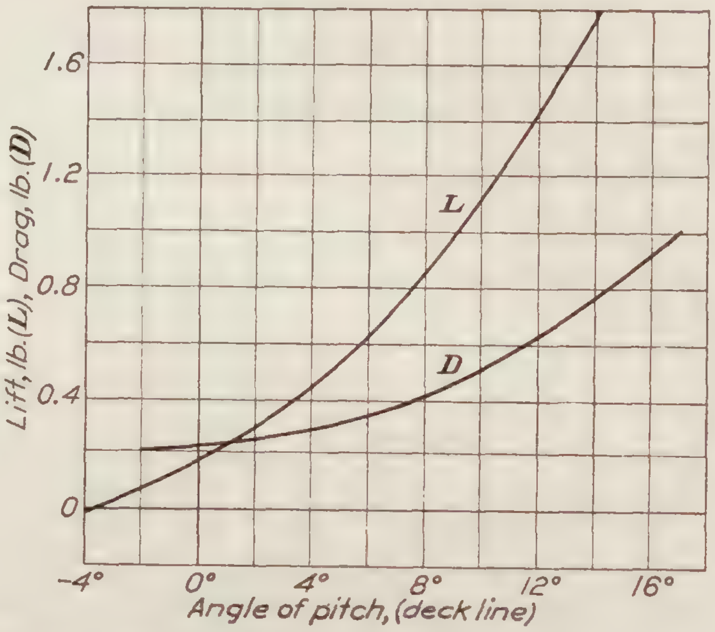
Lift and drag on NC-1 hull, stern No. 2. V=58.7 f. p. s. (Ref. W. T. R. No. 64)

G3



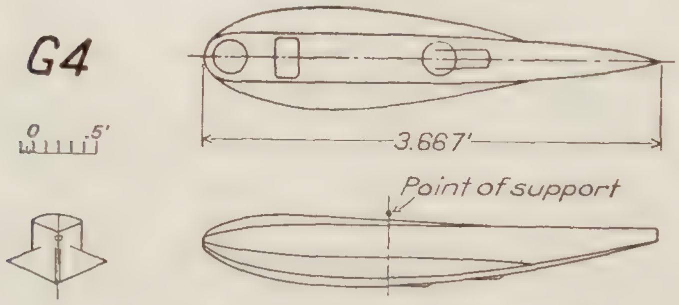
0° pitch and yaw S = .3850 sq. ft.

V, f.p.s.	44.0	58.7	73.3	88.0	102.7
D, lb.	.1271	.2098	.3165	.4297	.5594
D/S, lb./sq.ft.	.3300	.5450	.8220	1.1160	1.4530



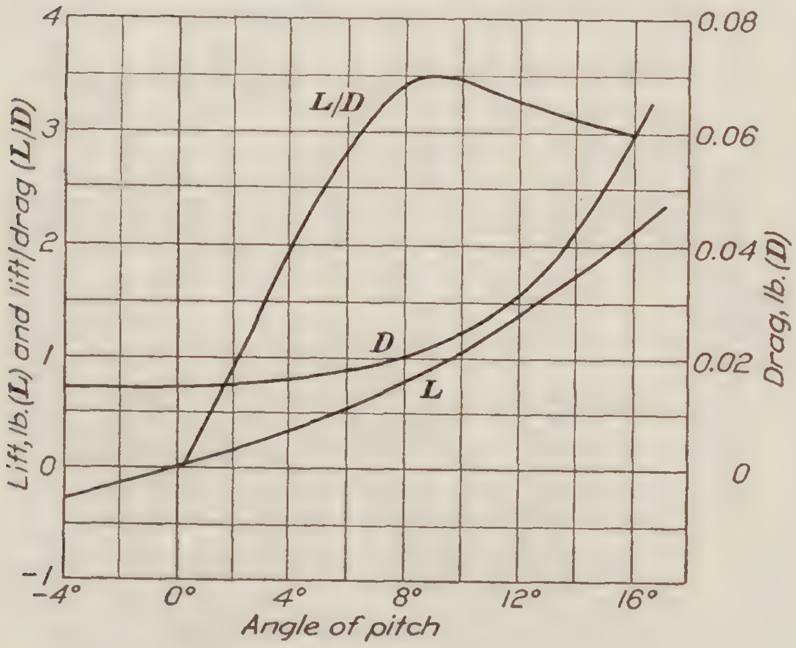
Lift and drag on NC-1 hull, stern No. 3. V=58.7 f. p. s. (Ref. W. T. R. No. 64)

G4



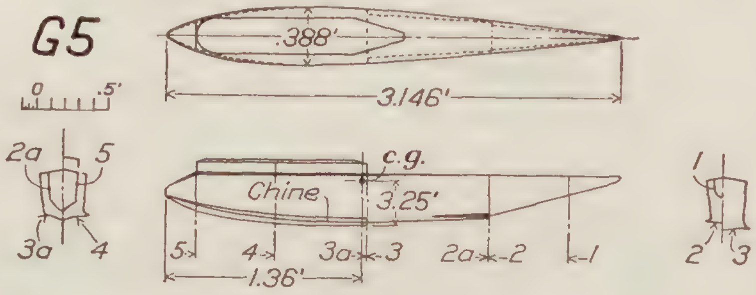
0° pitch and yaw S = .2720 sq. ft.

V, f.p.s.	58.7	73.3	88.0	102.7
D, lb.	.1190	.1890	.2770	.3800
D/S, lb./sq.ft.	.4370	.6950	1.0184	1.3971



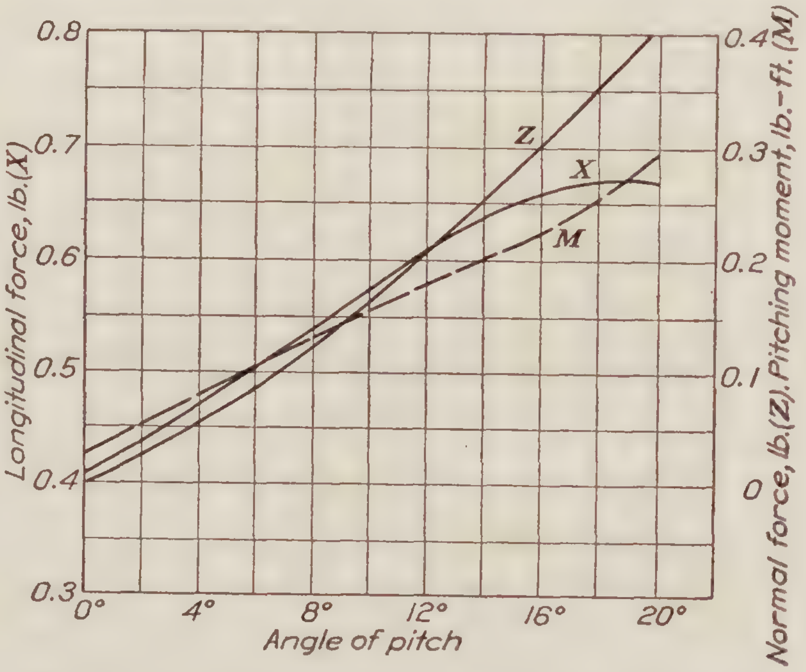
Lift and drag on F-5-L seaplane hull. V=58.7 f. p. s. (Ref. W. T. R. No. 83)

G5



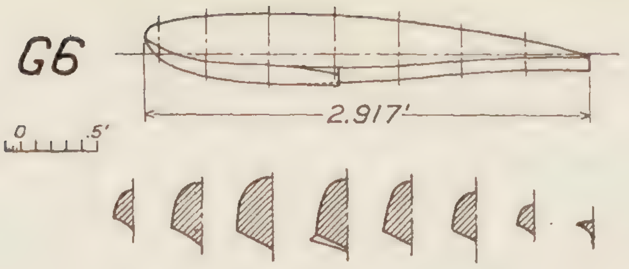
0° pitch and yaw S = .1400 sq. ft.

V, f.p.s.	40	50	60	70	80
D, lb.	.0413	.0662	.0953	.1283	.1650
D/S, lb./sq.ft.	.2950	.4730	.6810	.9164	1.1780



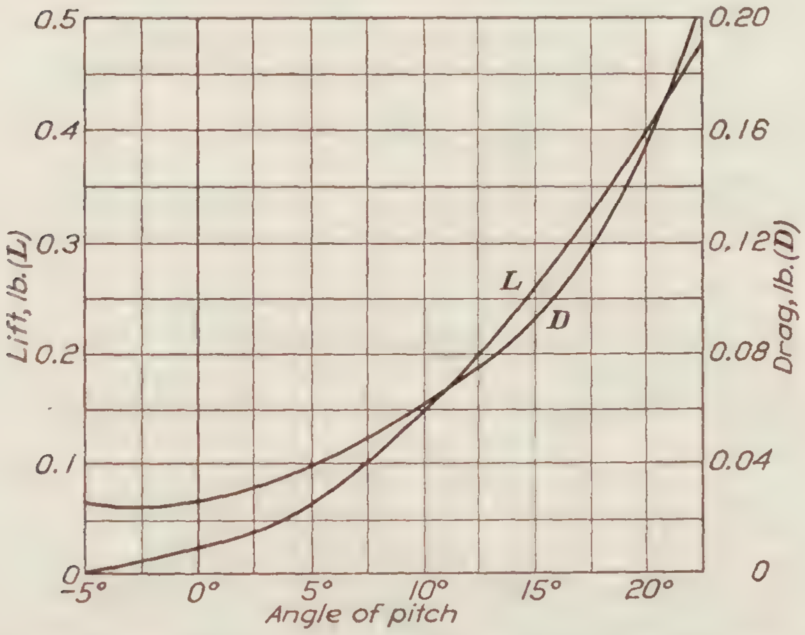
Forces and moments in pitch on hull. V=40 f. p. s. (Ref. R. and M. No. 223)

G6



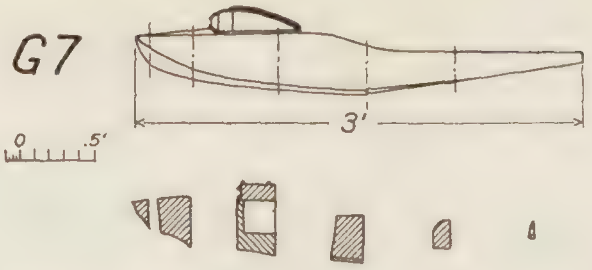
0° pitch and yaw S = .1700 sq. ft.

V, f.p.s.	40	50	60	70	80
D, lb.	.0273	.0445	.0645	.0877	.1130
D/S, lb./sq.ft.	.1606	.2618	.3794	.5159	.6647



Lift and drag on R. A. E. seaplane hull. V=40 f. p. s. (Ref. R. and M. No. 461)

G7

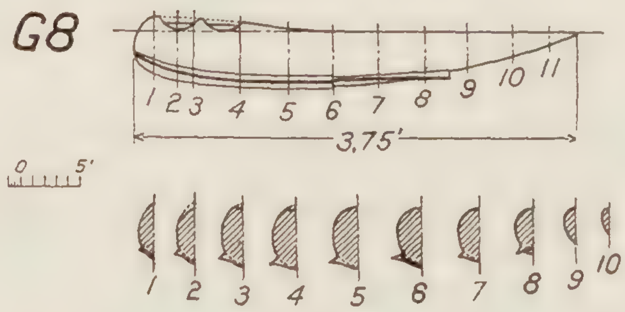


0° pitch and yaw

V, f.p.s.	30	40	50	60	70	80
With cabin				S = .257 sq. ft.		
D, lb.	.0428	.0822	.1264	.1810	.2478	.3233
D/S, lb./sq.ft.	.1665	.3198	.4918	.7043	.9642	1.2580
Without cabin				S = .184 sq. ft.		
D, lb.	.0300	.0505	.0775	.1111	.1502	.1976
D/S, lb./sq.ft.	.1630	.2745	.4212	.6038	.8163	1.0739

Drag on NT-2B seaplane hull. (Ref. R. and M. No. 461)

G8

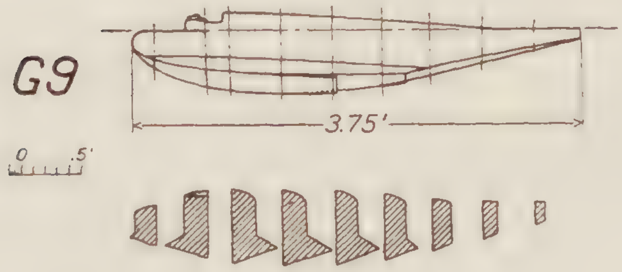


0° pitch and yaw S = .186 sq. ft.

V, f.p.s.	30	40	50	60	70	80
D, lb.	.0279	.0475	.0715	.1011	.1381	.1810
D/S, lb. sq.ft.	.1500	.2554	.3844	.5435	.7425	.9731

Drag on 30-foot A. D. seaplane hull. (Ref. R. and M. No. 461)

G9

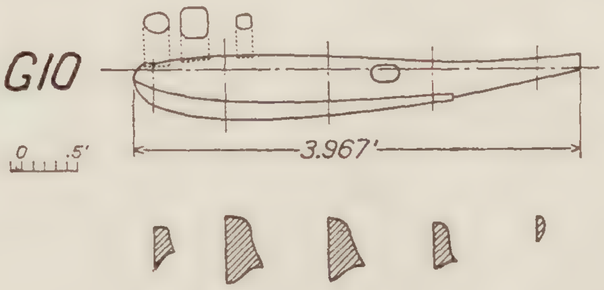


0° pitch and yaw S = .2760 sq. ft.

V, f.p.s.	30	40	50	60	70	80
D, lb.	.0414	.0711	.1108	.1562	.2130	.2695
D/S, lb./sq.ft.	.1500	.2576	.4014	.5659	.7717	.9764

Drag on F-3 seaplane hull. (Ref. R. and M. No. 461)

G10

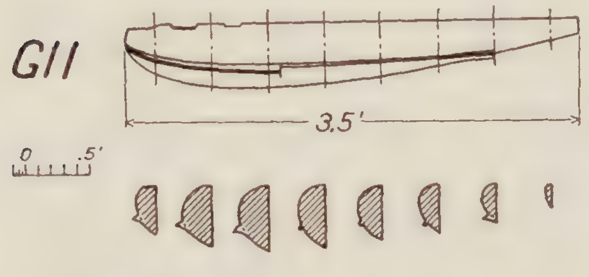


0° pitch and yaw S = .2520 sq. ft.

V, f.p.s.	30	40	50	60	70	80
D, lb.	.0313	.0532	.0821	.1171	.1591	.2051
D/S, lb./sq.ft.	.1242	.2111	.3258	.4647	.6313	.8139

Drag on N-4A seaplane hull. (Ref. R. and M. No. 461)

G11

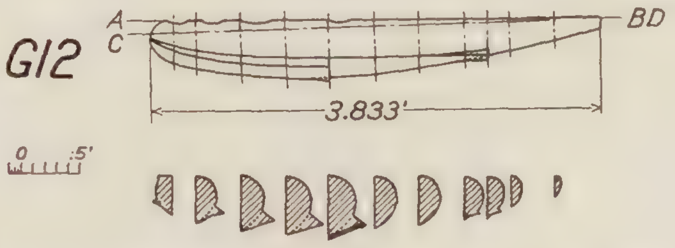


0° pitch and yaw S = .237 sq. ft.

V, f.p.s.	30	40	50	60	70	80
D, lb.	.0285	.0488	.0750	.1071	.1449	.1880
D/S, lb./sq.ft.	.1203	.2059	.3165	.4519	.6114	.7932

Drag on N-4 seaplane hull. (Ref. R. and M. No. 461)

G12

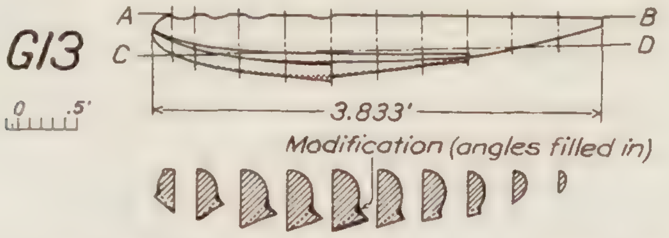


0° pitch and yaw S = .207 sq. ft.

V, f.p.s.	30	40	50	60	70	80
Line AB parallel to wind						
D, lb.	.0329	.0588	.0903	.1284	.1733	.2253
D/S, lb./sq.ft.	.1589	.2841	.4362	.6203	.8372	1.0884
Line CB parallel to wind						
D, lb.	.0367	.0635	.0978	.1397	.1853	.2420
D/S, lb./sq.ft.	.1773	.3068	.4725	.6749	.8952	1.1691

Drag on P-5A seaplane hull. (Ref. R. and M. No. 461)

G13

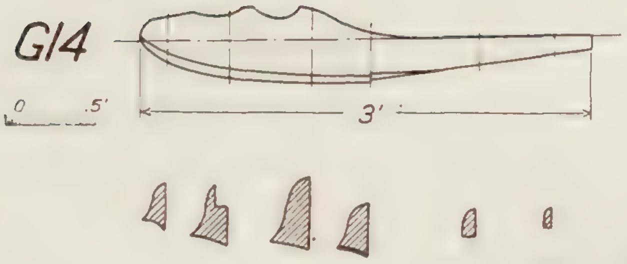


0° pitch and yaw S=.207 sq. ft.

V, f.p.s.	30	40	50	60	70	80
P-5 Line AB parallel to wind						
D, lb.	.0289	.0492	.0750	.1073	.1420	.1828
D/S, lb./sq. ft.	.1396	.2377	.3623	.5184	.6860	.8831
P-5 Line CD parallel to wind						
D, lb.	.0313	.0549	.0815	.1150	.1566	
D/S, lb./sq. ft.	.1512	.2652	.3937	.5556	.7565	
P-5 (modified) Line AB parallel to wind						
D, lb.	.0282	.0488	.0750	.1060	.1440	.1840
D/S, lb./sq. ft.	.1362	.2357	.3623	.5121	.6957	.8889
P-5 (modified) Line CD parallel to wind						
D, lb.	.0292	.0509	.0785	.1130	.1529	.1998
D/S, lb./sq. ft.	.1411	.2459	.3792	.5459	.7386	.9652

Drag on P-5 and P-5 (modified) seaplane hulls. (Ref. R. and M No. 461)

G14

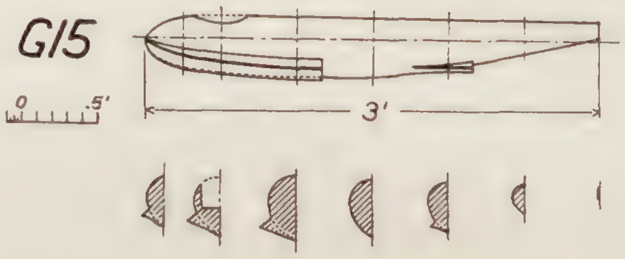


0° pitch and yaw S=.144 sq. ft.

V, f.p.s.	30	40	50	60	70	80
D, lb.	.2510	.0442	.0691	.0994	.1380	.1768
D/S, lb./sq. ft.	.1743	.3069	.4799	.6903	.9583	1.2278

Drag on NT-T seaplane hull. (Ref. R. & M. No. 461)

G15



0° pitch and yaw S=.139 sq. ft.

V, f.p.s.	30	40	50	60	70	80
D, lb.	.0218	.0372	.0553	.0794	.1070	.1400
D/S, lb./sq. ft.	.1568	.2676	.3978	.5712	.7698	1.0072

Drag on Supermarine N-1B hull. (Ref. R. and M. No. 461)

REPORT No. 237

TESTS ON THIRTEEN NAVY TYPE MODEL PROPELLERS

By W. F. DURAND
Stanford University

REPORT No. 237

TESTS OF THIRTEEN NAVY TYPE MODEL PROPELLERS

By W. F. Durand

PURPOSE OF TEST

The tests on these model propellers were conducted at Stanford University under research authorization of the National Advisory Committee for Aeronautics and were undertaken for the purpose of determining the performance coefficients and characteristics for certain selected series of propellers of form and type as commonly used in recent Navy designs.

The first series includes seven propellers of pitch ratio varying by 0.10 from 0.50 to 1.10, the area, form of blade, thickness, etc., representing an arbitrary standard propeller which had shown good results.

The second series covers changes in thickness of blade section, other things equal, and the third series, changes in blade area, other things equal.

These models are all of the standard 36-inch diameter employed in this laboratory.

The dimensions of these model forms are as shown in Figures 1 to 14.

It will be noticed that propellers A to G form the series on pitch ratio, C, N, I, J the series on thickness of section, and K, M, C, L the series on area.

METHOD OF TEST

The methods followed in these tests were similar to those of like tests previously reported, and need not be more particularly described here.

RESULTS

The results are presented in tabular and graphical form as follows:

Tabular results.—In Table I are given the observed values for the following quantities:

(*a*) The dynamic wind pressure $\rho V^2/2$ in pounds per square foot.

(*b*) The wind velocity in feet per second V.

(*c*) The revolutions per minute (N).

(*d*) The value of the slip function V/nD.

(*e*) The thrust in pounds (T).

(*f*) The torque in foot-pounds (Q) from which are calculated

(*g*) Values of the thrust coef. $C_T=\frac{T}{\rho n^2\,D^4}$.

(*h*) Values of the power coef. $C_{P1}=\frac{P}{\rho n^3\,D^5}$.

(*i*) Values of the power coef. $C_{P2}=\frac{P}{\rho V^3\,D^2}$.

(*j*) Values of the power coef. $C_{P3}=\frac{P}{\rho V^5\,n^2}$.

In addition, in Table II are given, as derived from smooth curves drawn through and among the observed points, values of the following:

(*a*) The thrust coef. $\frac{T}{\rho n^2\,D^4}$.

(*b*) The power coef. $\frac{P}{\rho n^3\,D^5}$.

(*c*) The efficiency η.

Graphical results.—In Figures 15 to 27 are shown for each propeller the following:

(*a*) The observed points for the thrust coef. $\frac{T}{\rho n^2 D^4}$.

(*b*) The observed points for the power coef. $\frac{P}{\rho n^3 D^5}$.

(*c*) The smooth curve through and among the points of (*a*) and giving the adjusted or most probable values as in Table II.

(*d*) The smooth curve through and among the points of (*b*) and giving the adjusted or most probable values as in Table II.

(*e*) The curve of values of the efficiency η as derived from the value of the coefficients of thrust and power, as in Table II.

DISCUSSION

The slip function V/nD is otherwise $(V/n)\div D$ and this is the ratio of the advance per revolution to the diameter. If the propeller blade consisted simply of an ideally thin true helicoidal surface screwing through the air without slip or action on the air, the advance per revolution would be equal to the pitch of the helicoidal surface. In such case there would be developed, of course, no thrust on or by the propeller. In an actual propeller the advance per revolution which produces no thrust gives an equivalent or virtual pitch and the ratio of this to diameter gives a form of equivalent or virtual pitch ratio. This will obviously give a point on the axis of V/nD where the thrust is zero and will thus furnish one limit of the various performance curves for the propeller. The other limit will likewise be found at the point where $V/nD=0$ or where the speed of advance $V=0$.

Turning to the values as given in the tables and figures, it is seen that in all cases the value of V/nD for $T=0$ is greater than the nominal or face pitch ratio, and in consequence the value of the virtual pitch based on advance for $T=0$ is in all cases greater than the face or nominal pitch. This is, of course, a well-known characteristic of actual propellers resulting from the aerodynamic properties of the standard form of propeller section with a practically plane driving face and a definitely rounded back. The amount of increase in pitch, as indicated by the value of V/nD for $T=0$ as compared with the nominal pitch ratio, is seen in general to be of the order of 20 to 40 per cent, the increase being greater for thick blades than for thin, as would naturally be expected.

The general character of the coefficients C_T, C_{P_I}, and of the efficiency η is plainly shown by the diagrams, Figures 15 to 27. The coefficient C_T begins on the axis of V/nD at the point for $T=0$ and rises sloping to the left, nearly straight at first and then curving over more definitely to some final limit value for $V/nD=0$. The coefficient C_{P_I} starts with a definite value for the V/nD value which gives $T=0$ and rises at first steeply and then curves more and more definitely toward the horizontal until over the working range of the propeller it is often nearly horizontal. In general, furthermore, these curves reach a maximum value for some small value of V/nD and then droop slightly to the terminal value for $V/nD=0$.

The curve of η begins, of course, at 0 where $T=0$ on the right and ends at 0 where $V=0$ $(V/nD=0)$ on the left. It rises, at first rapidly, to a maximum usually at a value of V/nD near or somewhat less than that equal to the nominal pitch ratio, and thence it declines more gradually to the origin where $V=0$.

Comparing now the values for the propellers A to G, constituting a series with pitch ratio advancing from 0.50 to 1.10, the increase in range along the axis of V/nD, with advancing pitch will be noted in the various diagrams. Likewise, for any given value of V/nD, the values of C_T and of C_{P_I} are seen to increase continuously and at a nearly uniform rate based on increase of pitch ratio.

For propellers within this series (A to G, inclusive), the maximum or peak efficiency is greater for propellers of higher pitch ratios.

For any given value of V/nD there is but one propeller which is operating at its maximum efficiency. However, its efficiency is not the highest which can be obtained at that value of

V/nD. There is one other propeller, having a higher pitch ratio, which gives the highest possible efficiency at the given V/nD for propellers of the particular form used in this series. This is clearly shown on Figure 28, where curve No. 1 is drawn through the maximum or peak efficiency of each propeller, while curve No. 2 shows the maximum possible efficiency for each V/nD.

Referring next to the results for models K, M, C, L, constituting a series on increasing blade area, it will be noted that with the form and proportions of blade section employed there is but slight variation in the value of V/nD for $T=0$. The values of C_T and C_{Pl} for any given value of V/nD increase, however, continuously with increase in area, and according to a nearly linear law over the range of area represented by these models. For C_T there is, as must be expected, an evident though small decrease in the rate of increase of value and, of course, with further increase in width these values would rapidly approach a limit. The point of special interest in these results lies in the fact that with the generally oval form of blade contour employed, and with the maximum width varying from about $0.07D$ to $0.10D$, the values of the coefficients increase nearly in proportion to the area.

An examination of the values for efficiency will show, however, that in detail and over the working range of V/nD the rate of increase in the value of the power coefficient is greater than that for the thrust coefficient and that in consequence, over this range of V/nD, increase in area is accompanied generally with decrease in efficiency. This is entirely in accord with normal expectation and likewise with previous tests relating to the same point.

However, as there is some tendency toward an increase of V/nD for $T=0$ with increased area, it follows that the efficiency for very large values of V/nD may be greater for large area than for small. In consequence the efficiency curves tend to cross at large values of V/nD, thus reversing the efficiency relation which holds over the working range.

The actual variation of efficiency over the working range for these propellers is noted to lie between 3 and 5 per cent for an area increase of 50 per cent.

In comparing the results for these four models it will be noted that the area increments are not equal, the successive areas being in the ratio 0.80, 0.92, 1.00, 1.20.

As a further point of interest, it will be noted that for area change the variation in the values of C_T and C_{P1} is relatively small at large values of V/nD and large at small values.

Turning next to the results for models C, H, I, J, constituting a series on blade thickness, it will be noted that there is a marked change in the values of V/nD for $T=0$, the value increasing with increase of thickness as would be expected. Likewise, for any given value of V/nD, the values of C_T and C_{P1} continuously increase with increase in thickness, at least over the range represented in these models. It will also be noted that the increase in the values of the coefficients is relatively large for large values of V/nD and that it becomes markedly less for small values, showing a tendency to disappear at extreme values. It will also be noted that this particular tendency is the reverse of that noted in connection with increase in area, where the large rate of change is found for small values of V/nD and the small rate for large values.

Likewise over the working range of V/nD and, as would be expected, the value of the power coefficient increases with thickness more rapidly than that of the thrust coefficient and it results that the efficiency continuously decreases as the thickness is increased. Here, again, the point of special interest is the relatively small change in efficiency lying within 2 per cent, resulting from a change of 30 per cent in the thickness.

Likewise, since with increased thickness the value of V/nD for $T=0$ is increased, it follows that for very large values of V/nD the efficiency will be greater for the thick blade than for the thin and that in general two efficiency curves for blades of differing values of the thickness will cross and thus for very large values of V/nD reverse the relations which hold over the working range.

In general the results found for the thirteen models which the present investigations covers, are entirely in accord with results found previously for models of the same general form and proportion. The results of the present investigation confirm, therefore, generally similar results for like models and furnish added series of performance coefficients for propellers of the form and proportion covered by them.

TABLE I

OBSERVED VALUES

PROPELLER A

No.	$\frac{1}{2}\rho V^2$	V	N	T	Q	V/nD	C_T	C_{P1}	C_{P2}	C_{P3}
1	2.786	49.64	1,456	0.00	0.597	0.682	0.00	0.0116	0.037	0.079
2	2.867	50.36	1,588	1.323	0.954	.634	.0103	.0156	.061	.152
3	2.861	50.32	1,712	2.977	1.426	.588	.0200	.0200	.098	.285
4	2.925	50.86	1.899	5.294	2.032	.536	.0289	.0232	.151	.525
5	2.899	50.63	2,093	8.272	2.768	.484	.0371	.0260	.229	.979
6	3.088	52.26	2,334	11.91	3.685	.448	.0430	.0278	.310	1.546
7	3.122	52.54	2,560	16.21	4.727	.410	.0486	.0297	.431	2.564
8	3.196	53.14	2,805	21.17	5.808	.379	.0528	.0304	.558	3.889
9	3.240	53.48	3,022	26.79	6.992	.354	.0576	.0315	.710	5.668
10	3.249	53.56	3,264	33.07	8.386	.328	.0609	.0324	.918	8.536
11	0.126	10.53	1,756	13.23	2.473	.119	.0839	.0329	----------	----------
12	0.234	14.35	2,375	24.25	4.560	.121	.0841	.0331	----------	----------

PROPELLER B

1	3.169	51.16	1,319	0.00	0.5418	0.775	0.00	0.0123	0.026	0.044
2	3.088	51.32	1,426	1.320	.9742	.720	.0123	.0190	.051	.098
3	3.141	51.85	1,556	2.979	1.487	.666	.0234	.0245	.083	.187
4	3.162	52.07	1.719	5.294	2.145	.606	.0341	.0290	.130	.354
5	3.231	52.69	1,905	8.272	2.974	.553	.0435	.0328	.194	.634
6	3.311	53.35	2,114	11.89	4.022	.505	.0508	.0360	.279	1.096
7	3.492	54.78	2,338	16.20	5.156	.468	.0566	.0377	.368	1.680
8	3.523	55.03	2,547	21.17	6.371	.432	.0623	.0393	.488	2.613
9	3.537	55.20	2,769	26.79	7.809	.399	.0669	.0409	.644	4.045
10	3.541	55.29	2,972	33.07	9.184	.372	.0718	.0418	.812	5.869
11	3.672	56.31	3,334	44.10	11.83	.338	.0761	.0428	1.109	9.708
12	0.180	12.45	1,831	16.98	3.433	.136	.0969	.0410	----------	----------

PROPELLER C

1	3.541	55.39	1,239	----------	0.4376	0.894	----------	0.0115	0.016	0.020
2	2.858	50.08	1,132	0.00	----------	.885	0.00	----------	----------	----------
3	3.563	55.58	1,347	----------	.8896	.825	----------	.0198	.035	.052
4	2.875	50.24	1,248	1.326	----------	.805	.0166	----------	----------	----------
5	3.609	55.98	1,466	----------	1.467	.764	----------	.0276	.062	.106
6	2.966	51.02	1,387	2.980	----------	.736	.0302	----------	----------	----------
7	3.609	55.98	1,619	----------	2.196	.692	----------	.0339	.103	.215
8	3.141	52.41	1,553	----------	2.161	.675	----------	.0365	.119	.261
9	3.033	51.60	1,559	5.294	----------	.662	.0425	----------	----------	----------
10	3.709	56.80	1,814	8.272	3.165	.626	.0486	.0390	.159	.406
11	3.168	52.68	1,754	----------	3.094	.601	----------	.0410	.189	.525
12	3.082	52.01	1,751	8.272	----------	.594	.0526	----------	----------	----------
13	3.798	57.55	2,020	11.91	4.313	.570	.0566	.0429	.232	.713
14	3.181	52.84	1,958	11.91	----------	.539	.0606	----------	----------	----------
15	3.888	58.23	2,226	16.21	5.542	.524	.0634	.0454	.317	1.158
16	3.253	53.44	2,165	16.21	----------	.494	.0674	----------	----------	----------
17	4.050	59.50	2,438	----------	6.880	.488	----------	.0471	.405	1.702
18	3.388	54.53	2,389	21.17	----------	.456	.0723	----------	----------	----------
19	4.041	59.30	2,644	26.79	8.354	.449	.0742	.0484	.535	2.653
20	4.086	59.66	2,857	33.07	9.924	.418	.0785	.0493	.677	3.878
21	3.420	54.78	2,820	33.07	----------	.389	.0811	----------	----------	----------
22	2.781	48.74	2,777	35.51	9.752	.351	.0874	.0503	1.163	9.444
23	1.904	40.35	2,813	39.47	10.091	.287	.0947	.0507	2.145	----------
24	.360	17.17	2,354	33.07	7.166	.145	.1086	.0493	----------	----------

PROPELLER D

1	3.100	52.27	1,051	0.00	0.401	0.994	0.00	0.0149	0.015	0.015
2	3.137	52.57	1,160	1.323	.929	.906	.0192	.0283	.038	.046
3	3.159	52.78	1,283	2.978	1.518	.822	.0354	.0378	.068	.101
4	3.221	53.31	1,449	5.294	2.348	.736	.0494	.0459	.115	.213
5	3.308	54.02	1,639	8.276	3.382	.659	.0604	.0517	.181	.416
6	3.370	54.51	1,841	11.91	4.570	.592	.0688	.0553	.266	.760
7	3.420	54.92	2,028	16.21	5.876	.539	.0765	.0581	.371	1.277
8	2.778	48.03	1,920	16.21	5.645	.500	.0812	.0592	.474	1.895
9	2.925	49.30	2,127	21.17	7.072	.464	.0864	.0605	.606	2.811
10	3.006	49.98	2,330	26.79	8.695	.429	.0911	.0620	.786	4.271
11	.125	9.91	1,270	11.02	2.544	.156	.1193	.0579	----------	----------

PROPELLER E

1	2.902	49.88	907	0.00	0.289	1.100	0.00	0.0140	0.011	0.009
2	2.898	49.88	1,007	----------	.877	.990	----------	.0346	.036	.036
3	2.898	50.27	1,020	1.323	----------	.986	.0246	----------	----------	----------
4	3.006	50.81	1,147	----------	1.564	.886	----------	.0475	.068	.087
5	2.911	50.42	1,147	2.977	----------	.879	.0439	----------	----------	----------
6	3.051	51.20	1,305	5.292	2.434	.785	.0593	.0572	.118	.192
7	3.064	51.56	1,492	8.274	3.52	.691	.0716	.0638	.193	.405
8	3.135	52.20	1,682	11.910	4.744	.621	.0814	.0679	.279	.725
9	3.222	52.92	1,875	16.210	6.103	.564	.0889	.0701	.391	1.025
10	3.244	53.15	2,075	21.170	7.611	.512	.0950	.0715	.532	2.030
11	3.238	53.04	2,273	26.79	9.257	.466	.0998	.0723	.708	3.260
12	3.411	54.77	2,661	38.58	12.627	.412	.1065	.0730	1.050	6.180
13	.234	14.13	1,811	22.05	5.590	.156	.1272	.0676	----------	----------

TABLE I—Continued

OBSERVED VALUES—Continued

PROPELLER F

No.	$\frac{1}{2}\rho V^2$	V	N	T	Q	V/nD	C_T	C_{P1}	C_{P2}	C_{P3}
1	3.146	52.66	877	0.00	0.296	1.201	0.00	0.0158	0.0091	0.006
2	3.190	53.06	988	1.323	.947	1.074	.0266	.0398	.0321	.028
3	3.168	52.87	1,102	2.979	1.664	.959	.0481	.0562	.0637	.069
4	3.177	52.94	1,256	5.294	2.602	.842	.0658	.0677	.1134	.160
5	3.267	53.68	1,436	8.274	3.765	.748	.0787	.0750	.1792	.320
6	3.330	54.22	1,614	11.91	5.126	.672	.0897	.0809	.2666	.590
7	3.389	54.69	1,802	16.19	6.580	.607	.0978	.0832	.3721	1.010
8	3.450	55.23	1,999	21.15	8.230	.553	.1041	.0848	.5016	1.642
9	3.483	55.49	2,198	26.79	10.000	.505	.1090	.0852	.6616	2.595
10	3.531	55.88	2,380	33.07	11.910	.469	.1146	.0865	.8384	3.811
11	.144	11.25	1,336	12.13	3.327	.168	.1326	.0762	----------	----------

PROPELLER G

1	3.163	52.95	814	0.00	0.2748	1.300	0.00	0.0171	0.0078	0.005
2	3.180	53.16	922	1.323	.9620	1.153	.0307	.0468	.0305	.023
3	3.195	53.27	1,049	2.979	1.755	1.016	.0534	.0660	.0635	.062
4	3.199	53.32	1,199	5.306	2.744	.889	.0729	.0790	.1124	.142
5	3.240	53.66	1,369	8.300	3.948	.784	.0876	.0872	.1810	.295
6	3.339	54.48	1,545	11.97	5.348	.705	.0990	.0926	.2643	.532
7	3.366	54.69	1,730	16.19	6.886	.632	.1069	.0951	.3770	.944
8	3.330	54.44	1,915	21.17	8.542	.569	.1142	.0966	.5245	1.620
9	3.321	54.37	2,102	26.79	10.326	.517	.1200	.0969	.7010	2.623
10	3.402	55.02	2,302	33.07	12.480	.478	.1234	.0976	.8940	3.915
11	.129	10.34	1,235	11.02	3.595	.167	.1331	.0909	----------	----------
12	.328	16.48	1,864	26.46	8.210	.177	.1403	.0911	----------	----------

PROPELLER H

1	3.141	52.09	1,134	0.00	0.4586	0.919	0.00	0.0143	0.018	0.022
2	3.199	52.56	1,250	1.323	.9490	.841	.0163	.0244	.041	.058
3	3.258	53.35	1,390	2.977	1.498	.767	.0299	.0315	.070	.119
4	3.145	52.12	1,521	5.292	2.232	.685	.0439	.0388	.121	.258
5	3.352	54.21	1,736	8.268	3.199	.624	.0535	.0433	.178	.458
6	3.433	54.86	1,941	11.91	4.348	.565	.0616	.0471	.261	.818
7	3.276	53.18	1,900	11.91	4.228	.560	.0634	.0471	.268	.855
8	3.321	53.62	2,106	16.21	5.465	.509	.0703	.0497	.377	1.456
9	3.402	54.32	2,323	21.17	6.818	.467	.0756	.0510	.501	2.297
10	3.505	55.14	2,533	26.79	8.278	.435	.0805	.0521	.633	3.345
11	3.631	56.12	2,755	33.07	9.913	.407	.0840	.0527	.782	4.721
12	.124	10.35	1,433	11.91	2.613	.144	.1114	.0512	----------	----------

PROPELLER I

1	2.435	45.28	959	0.00	0.504	0.945	0.00	0.0215	0.025	0.029
2	3.213	52.28	1,210	1.323	1.094	.864	.0171	.0296	.046	.062
3	3.510	54.75	1,377	2.977	1.651	.795	.0298	.0346	.069	.109
4	2.502	45.96	1,225	2.977	1.479	.750	.0372	.0387	.092	.163
5	3.569	55.21	1,524	5.292	2.373	.725	.0433	.0406	.107	.202
6	2.669	48.20	1,423	5.292	2.243	.678	.0506	.0449	.144	.313
7	3.352	53.48	1,674	8.268	3.290	.639	.0560	.0466	.179	.437
8	3.402	53.87	1,864	11.91	4.397	.578	.0650	.0502	.260	.779
9	3.768	49.00	1,813	11.91	4.173	.540	.0698	.0513	.326	1.117
10	3.816	57.22	2,317	21.17	7.137	.494	.0752	.0531	.440	1.805
11	3.948	58.26	2,729	33.07	10.203	.427	.0849	.0548	.704	3.861
12	2.907	49.61	2,630	33.07	9.704	.377	.0900	.0553	1.032	7.264
13	.353	17.42	2,363	33.07	7.470	.147	.1132	.0535	----------	----------

PROPELLER J

1	2.16	51.73	1,042	0.00	0.6408	0.993	0.00	0.0233	0.0238	0.0241
2	3.20	51.04	1,136	1.323	1.129	.897	.0185	.0330	.0457	.0568
3	3.245	52.04	1,285	2.977	1.689	.810	.0335	.0398	.075	.114
4	3.321	52.62	1,450	5.292	2.457	.726	.0467	.0454	.119	.225
5	3.402	54.12	1,663	8.268	3.385	.651	.0572	.0490	.178	.419
6	3.483	54.78	1,875	11.91	4.542	.584	.0650	.0518	.260	.762
7	3.447	54.05	2,054	16.21	5.738	.526	.0723	.0536	.368	1.331
8	3.447	53.61	2,234	21.17	7.080	.480	.0786	.0550	.497	2.158
9	3.564	54.51	2,440	26.79	8.552	.447	.0834	.0557	.626	3.138
10	3.364	54.61	2,650	33.07	10.174	.412	.0872	.0562	.803	4.736
11	0.267	14.92	2,070	26.47	6.076	.144	.1144	.0550	----------	----------

PROPELLER K

1	3.064	52.10	1,190	0.00	0.414	0.875	0.00	0.0120	0.018	0.023
2	3.073	52.25	1,327	1.323	.832	.788	.0148	.0195	.040	.065
3	3.159	53.00	1,490	2.977	1.388	.711	.0265	.0259	.072	.143
4	3.141	52.89	1,652	5.292	2.069	.640	.0384	.0314	.120	.292
5	3.186	53.26	1,873	8.268	2.954	.569	.0466	.0349	.189	.585
6	3.285	54.26	2,104	11.91	3.950	.516	.0534	.0371	.270	1.014
7	3.307	54.33	2,332	16.21	5.095	.466	.0591	.0389	.384	1.770
8	3.375	54.88	2,572	21.17	6.352	.427	.0634	.0399	.513	2.812
9	3.420	55.26	2,815	26.79	7.681	.393	.0671	.0403	.664	4.300
10	0.283	15.35	2,307	26.47	5.446	.133	.0920	.0396	----------	----------

TABLE I—Continued

OBSERVED VALUES—Continued

PROPELLER L

No.	$\frac{1}{2}\rho V^2$	V	N	T	Q	V/nD	C_T	C_{P1}	C_{P2}	C_{P3}
1	3.048	51.38	1,151	0.00	0.524	0.893	0.00	0.0159	0.022	0.028
2	3.119	51.99	1,257	1.323	1.028	.827	.0161	.0262	.046	.068
3	3.253	53.17	1,385	2.977	1.585	.767	.0300	.0334	.074	.126
4	3.343	53.90	1,540	5.292	2.378	.700	.0430	.0405	.118	.241
5	3.348	53.93	1,702	8.268	3.326	.634	.0552	.0465	.182	.453
6	3.429	54.61	1,892	11.91	4.4[illegible]	.577	.0644	.0509	.265	.796
7	3.523	55.46	2,104	16.21	5.7[illegible]	.527	.0710	.0532	.363	1.308
8	3.560	55.75	2,307	21.17	7.260	[illegible]3	.0772	.0554	.492	2.105
9	3.677	56.65	2,513	26.79	8.862	.451	.0823	.0570	.622	3.053
10	3.717	56.97	2,719	33.07	10.607	.419	.0868	.0583	.793	4.515
11	0.108	9.51	1,285	11.02	2.524	.148	.1242	.0596	-----	-----

PROPELLER M

1	3.312	53.23	1,217	0.00	0.472	0.875	0.00	0.0127	0.019	0.025
2	3.335	53.45	1,327	1.323	.940	.806	.0143	.0213	.041	.063
3	3.379	53.87	1,452	2.977	1.461	.742	.0269	.0277	.068	.124
4	3.402	54.10	1,613	5.292	2.175	.671	.0389	.0335	.111	.247
5	3.470	54.64	1,813	8.268	3.106	.603	.0481	.0378	.173	.476
6	3.294	54.17	2,018	11.91	4.190	.537	.0577	.0425	.274	.952
7	3.366	54.75	2,250	16.21	5.396	.487	.0634	.0442	.383	1.614
8	3.555	56.28	2,471	21.17	6.594	.456	.0686	.0448	.472	2.272
9	3.645	57.00	2,699	26.79	8.123	.422	.0728	.0462	.615	3.452
10	3.693	57.37	2,918	33.07	9.714	.393	.0769	.0473	.779	5.048
11	0.112	9.68	1,412	11.02	.238	.137	.1028	.0465	-----	-----

TABLE II

ADJUSTED VALUES

Prop.	A		B		C		D		E		F		G	
V/nD	C_{P1}	η	C_{P1}	η	C_{P1}	η	C_{P1}	η	C_{P1}	η	C_{P1}	η	C_{P1}	η
0.20	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
.25	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
.30	0.0326	0.594	0.0432	0.566	0.0506	0.549	-----	-----	-----	-----	-----	-----	-----	-----
.35	.0316	.637	.0422	.622	.0504	.601	-----	-----	-----	-----	-----	-----	-----	-----
.40	.0300	.669	.0406	.655	.0497	.644	0.0623	0.604	0.0730	0.586	0.0872	0.560	0.0975	0.543
.45	.0280	.689	.0386	.699	.0485	.680	.0613	.646	.0727	.628	.0867	.604	.0976	.587
.50	.0250	.690	.0361	.720	.0467	.711	.0597	.687	.0718	.667	.0860	.645	.0975	.626
.55	.0220	.660	.0330	.728	.0442	.739	.0577	.715	.0705	.701	.0850	.680	.0970	.661
.60	.0184	.571	.0295	.714	.0413	.755	.0550	.745	.0687	.732	.0835	.711	.0960	.694
.65	.0143	.323	.0255	.663	.0379	.763	.0520	.766	.0663	.756	.0812	.743	.0945	.722
.70	-----	-----	.0210	.557	.0338	.756	.0485	.779	.0632	.782	.0785	.767	.0925	.748
.75	-----	-----	-----	-----	.0290	.724	.0445	.782	.0597	.798	.0750	.790	.0896	.770
.80	-----	-----	-----	-----	.0233	.618	.0400	.768	.0557	.804	.0715	.806	.0864	.790
.85	-----	-----	-----	-----	-----	-----	.0349	.731	.0510	.800	.0670	.818	.0825	.806
.90	-----	-----	-----	-----	-----	-----	.0292	.641	.0460	.783	.0624	.818	.0782	.817
.95	-----	-----	-----	-----	-----	-----	.0224	.445	.0401	.732	.0570	.807	.0734	.828
1.00	-----	-----	-----	-----	-----	-----	-----	-----	.0331	.650	.0510	.775	.0678	.826
1.05	-----	-----	-----	-----	-----	-----	-----	-----	.0245	.471	.0439	.725	.0619	.814
1.10	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.0361	.640	.0552	.794
1.15	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.0267	.452	.0475	.751
1.20	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.0390	.677
1.25	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.0290	.504

ADJUSTED VALUES

Prop.	H		I		J	
V/nD	C_{P1}	η	C_{P1}	η	C_{P1}	η
0.40	0.0530	0.639	0.0553	0.632	0.0563	0.628
.45	.0519	.676	.0545	.670	.0558	.664
.50	.0503	.708	.0532	.703	.0546	.697
.55	.0480	.735	.0515	.730	.0531	.724
.60	.0452	.752	.0494	.749	.0512	.744
.65	.0418	.760	.0462	.758	.0492	.753
.70	.0379	.756	.0426	.756	.0468	.749
.75	.0335	.728	.0388	.730	.0441	.733
.80	.0287	.649	.0347	.668	.0408	.687

ADJUSTED VALUES

Prop.	K		L		M	
V/nD	C_{P1}	η	C_{P1}	η	C_{P1}	η
0.40	0.0403	0.657	0.0588	0.607	0.0468	0.649
.45	.0396	.691	.0570	.651	.0456	.685
.50	.0381	.722	.0547	.690	.0437	.717
.55	.0359	.751	.0520	.719	.0413	.745
.60	.0330	.767	.0486	.744	.0385	.762
.65	.0299	.770	.0450	.751	.0350	.762
.70	.0262	.748	.0405	.743	.0312	.747
.75	.0224	.689	.0355	.699	.0268	.695
.80	.0184	.544	.0296	.619	.0220	.575

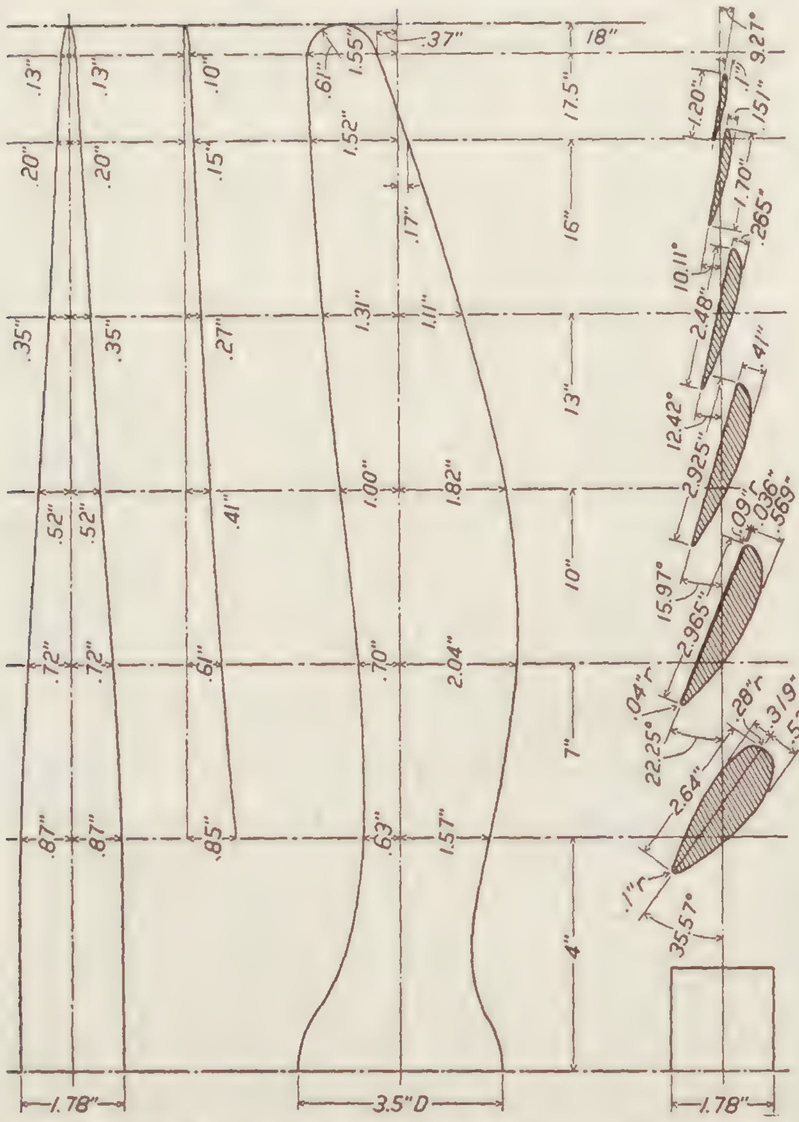


Fig. 1.—Propeller A. Diameter, 3 feet. Aspect ratio, 6. Maximum blade width, 3 inches. Pitch, 18 inches. Pitch ratio, 0.5. Camber ratio, minimum

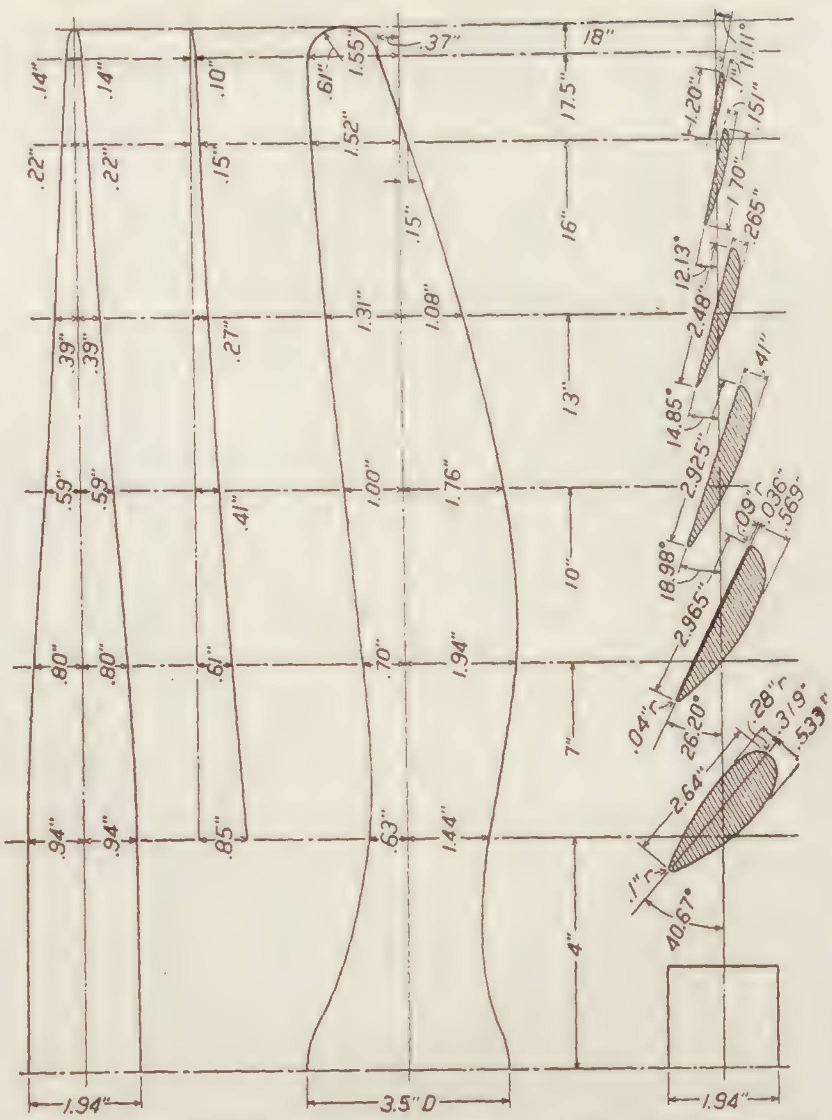


Fig. 2.—Propeller B. Diameter, 3 feet. Aspect ratio, 6. Maximum blade width, 3 inches. Pitch, 21.6 inches. Pitch ratio 0.6. Camber ratio, minimum

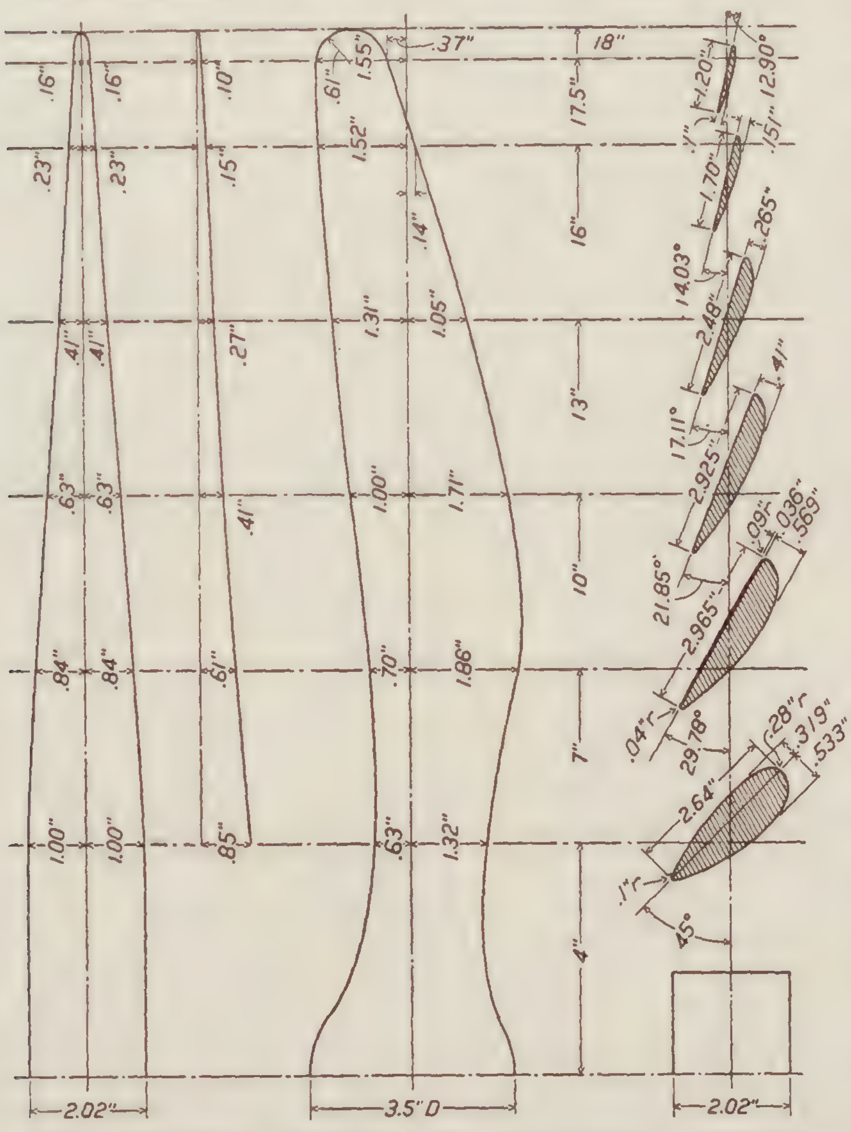


Fig. 3.—Propeller C. Diameter, 3 feet. Aspect ratio, 6. Maximum blade width, 3 inches. Pitch, 25.2 inches. Pitch ratio 0.7. Camber ratio, minimum

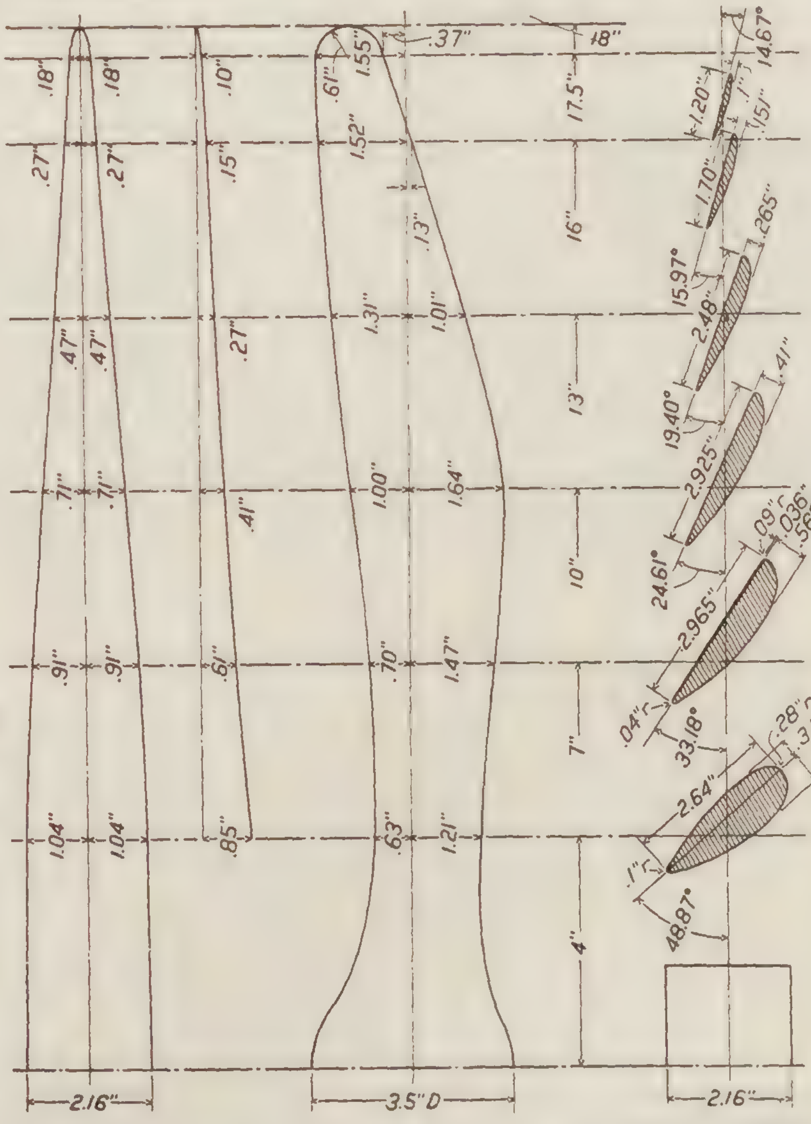


Fig. 4.—Propeller D. Diameter, 3 feet. Aspect ratio, 6. Maximum blade width, 3 inches. Pitch, 28.8 inches. Pitch ratio 0.8. Camber ratio, minimum

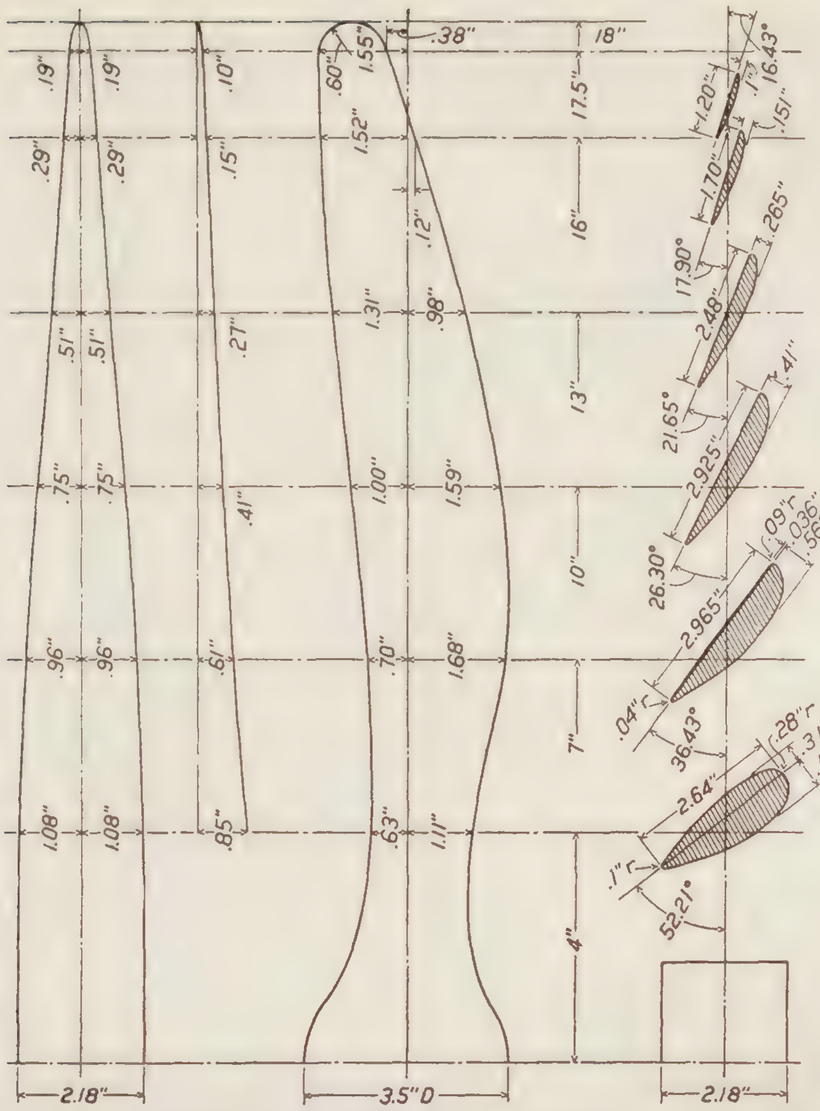


FIG. 5.—Propeller E. Diameter, 3 feet. Aspect ratio, 6. Maximum blade width, 3 inches. Pitch, 32.4 inches. Pitch ratio, 0.9. Camber ratio, minimum

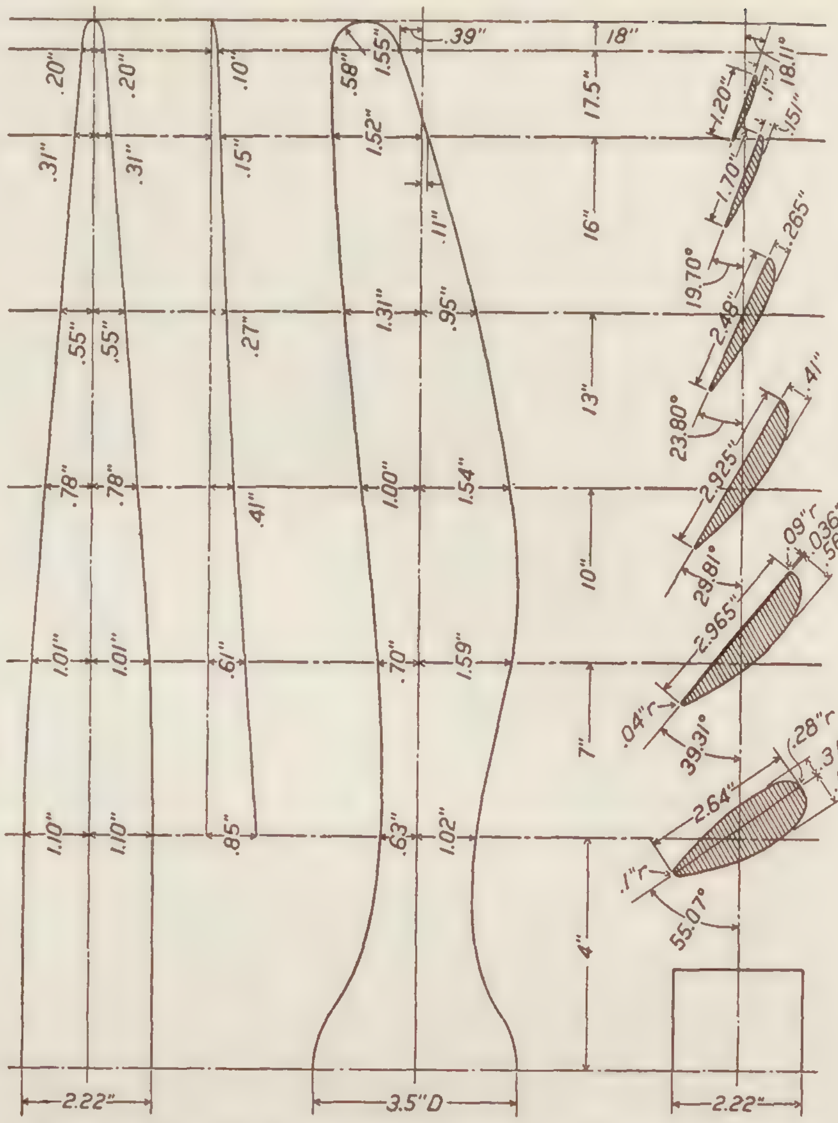


FIG. 6.—Propeller F. Diameter, 3 feet. Aspect ratio, 6. Maximum blade width, 3 inches. Pitch, 36 inches. Pitch ratio, 1. Camber ratio, minimum

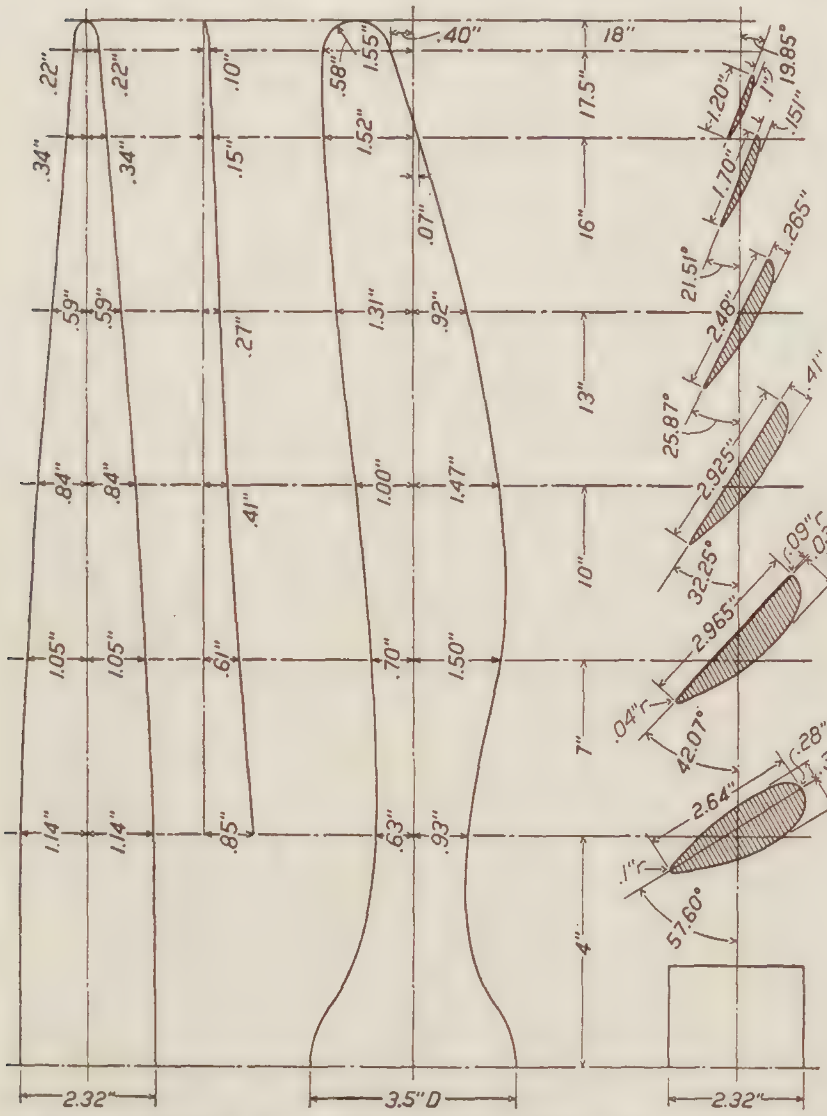


FIG. 7.—Propeller G. Diameter, 3 feet. Aspect ratio, 6. Maximum blade width, 3 inches. Pitch, 39.6 inches. Pitch ratio, 1.1. Camber ratio, minimum

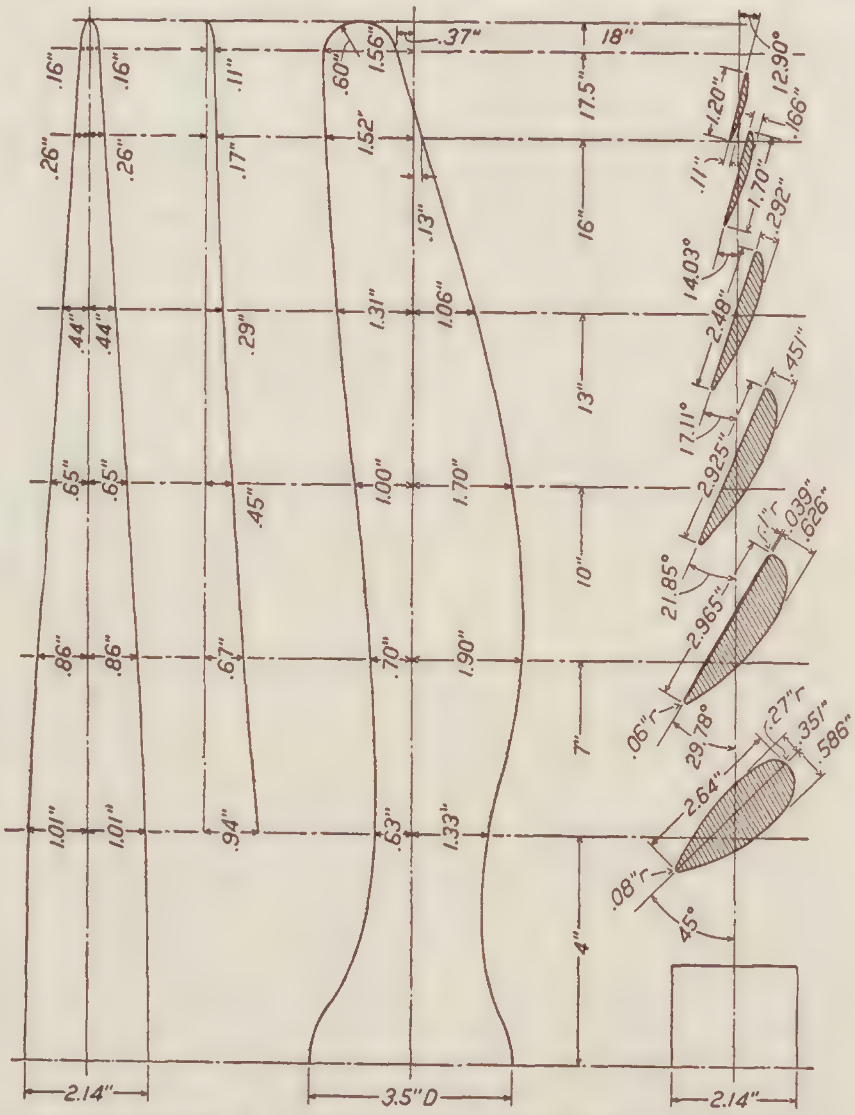


FIG. 8.—Propeller H. Diameter, 3 feet. Aspect ratio, 6. Maximum blade width, 3 inches. Pitch, 25.2 inches. Pitch ratio, 0.7. Camber ratio, minimum +10 per cent

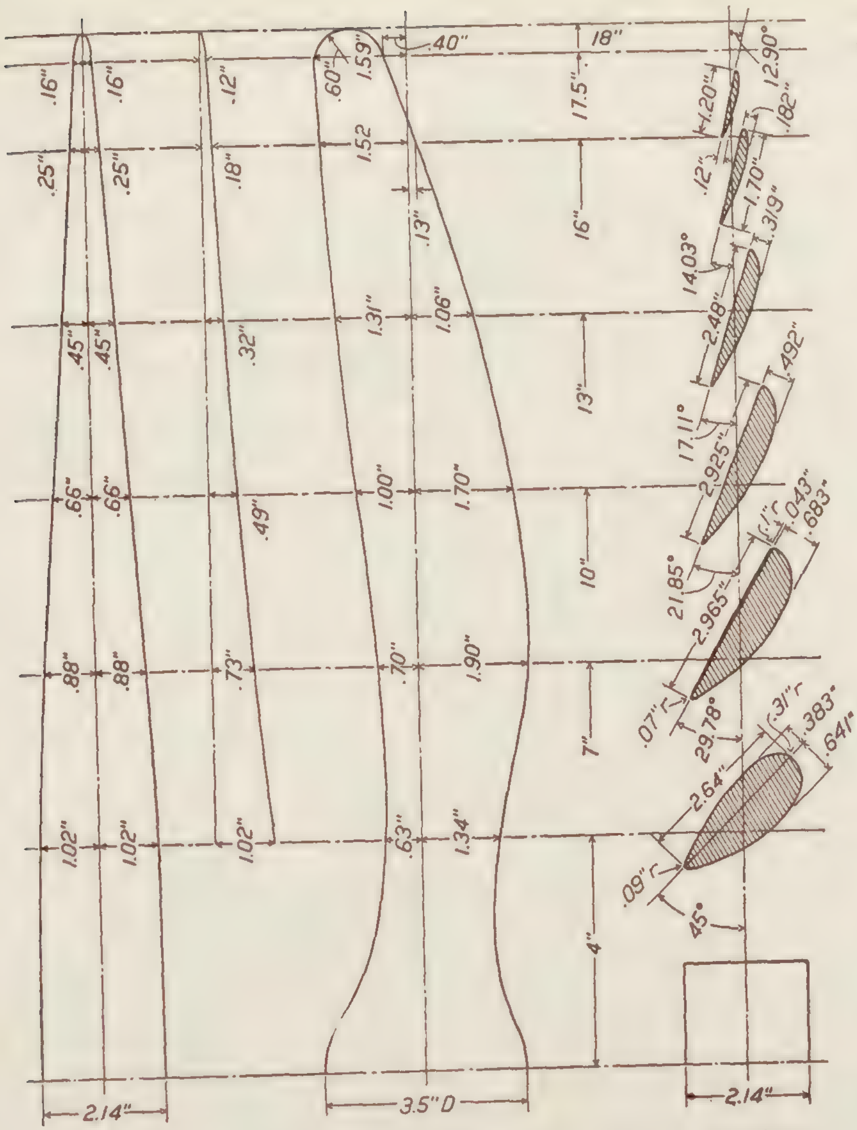


FIG. 9.—Propeller I. Diameter, 3 feet. Aspect ratio, 6. Maximum blade width, 3 inches. Pitch, 25.2 inches. Pitch ratio, 0.7. Camber ratio, minimum +20 per cent

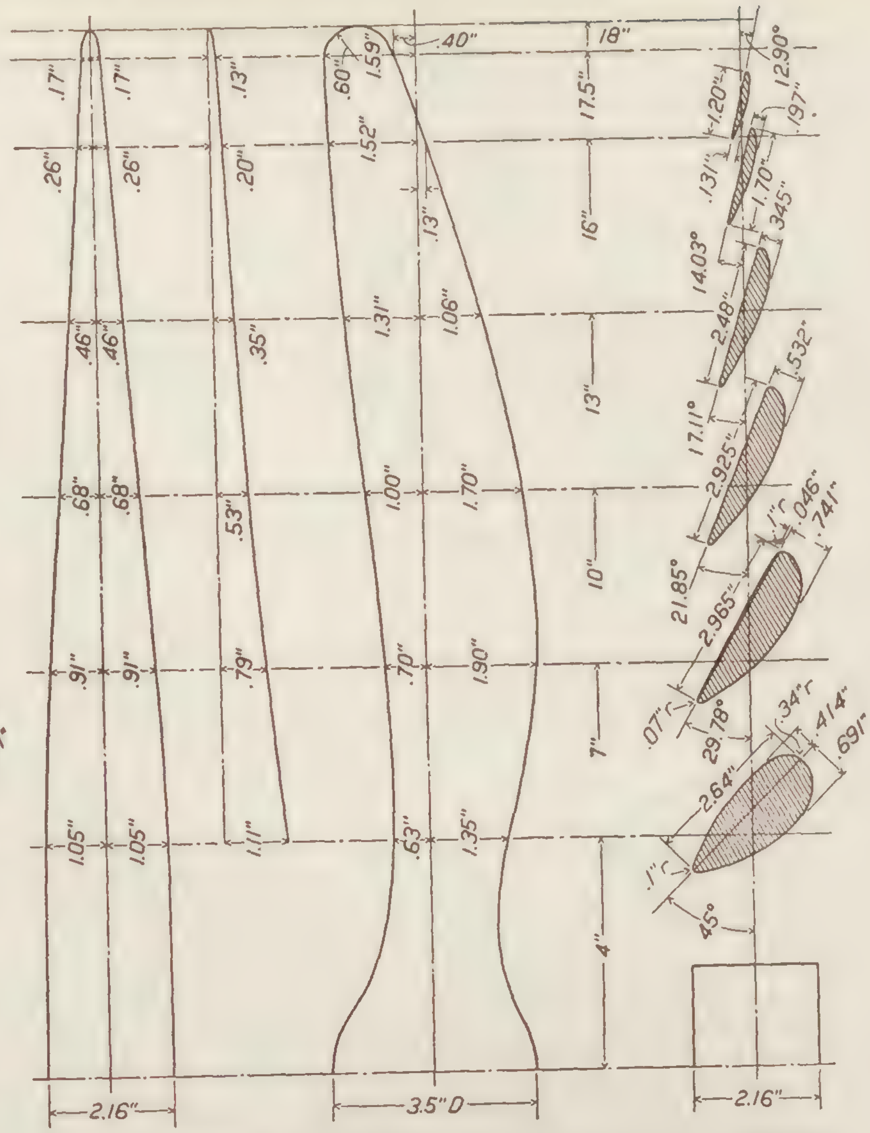


FIG. 10.—Propeller J. Diameter, 3 feet. Aspect ratio, 6. Maximum blade width, 3 inches. Pitch, 25.2 inches. Pitch ratio, 0.7. Camber ratio, minimum +30 per cent

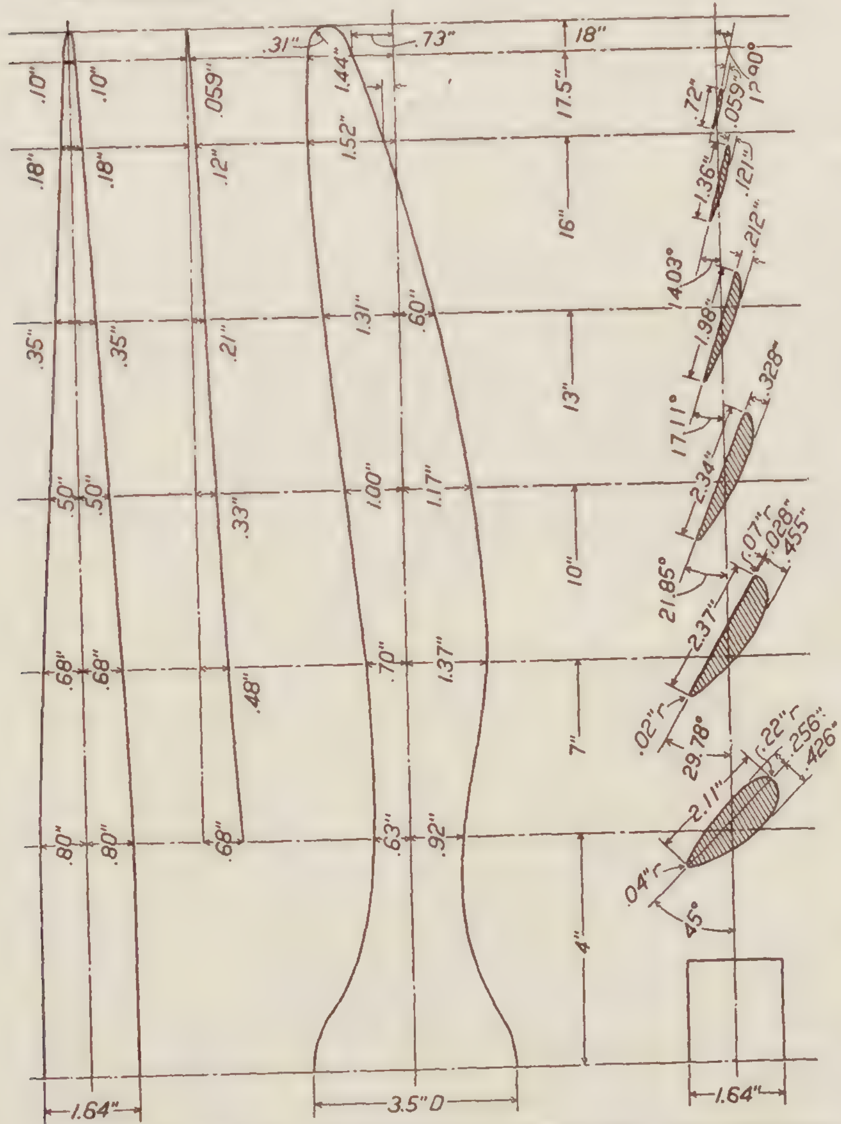


FIG. 11.—Propeller K. Diameter, 3 feet. Aspect ratio, 7.5. Maximum blade width, 2.4 inches. Pitch, 25.2 inches. Pitch ratio, 0.7. Camber ratio, minimum

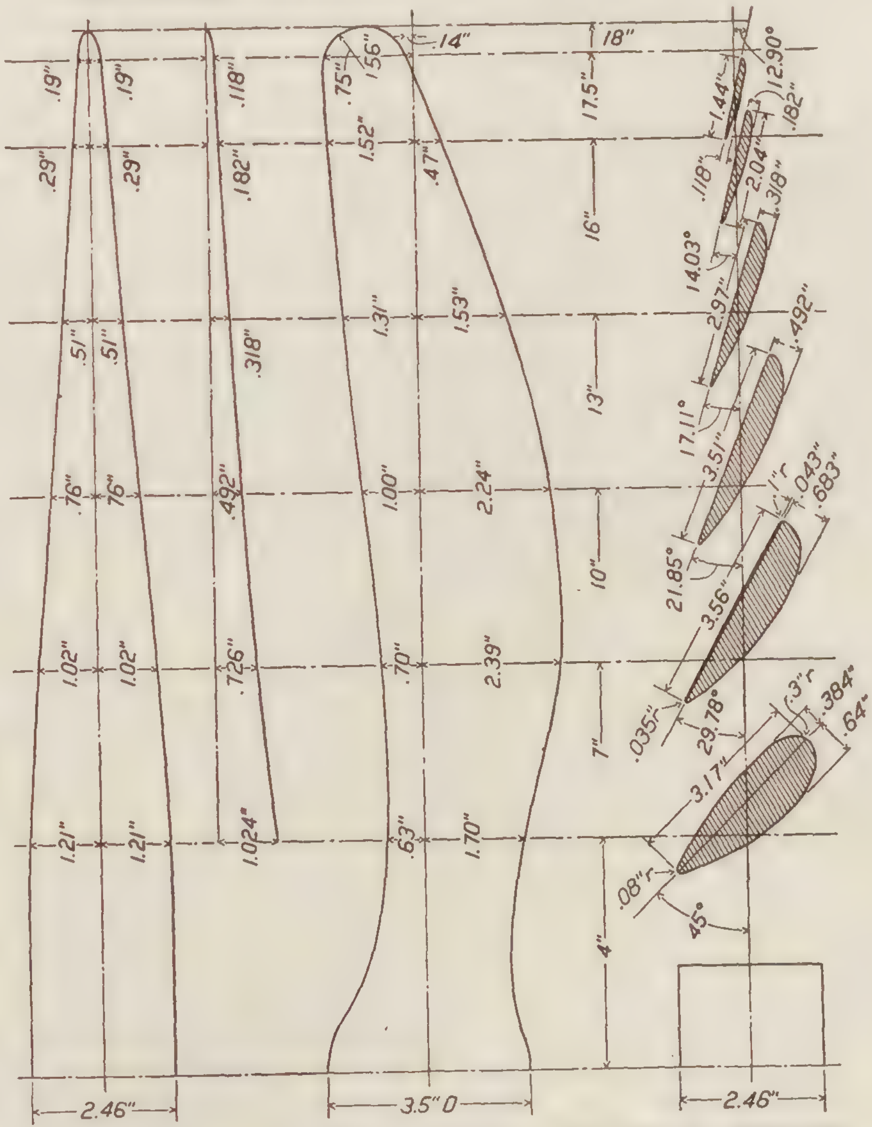


FIG. 12.—Propeller L. Diameter, 3 feet. Aspect ratio, 5. Maximum blade width, 3.6 inches. Pitch, 25.2 inches. Pitch ratio, 0.7. Camber ratio, minimum

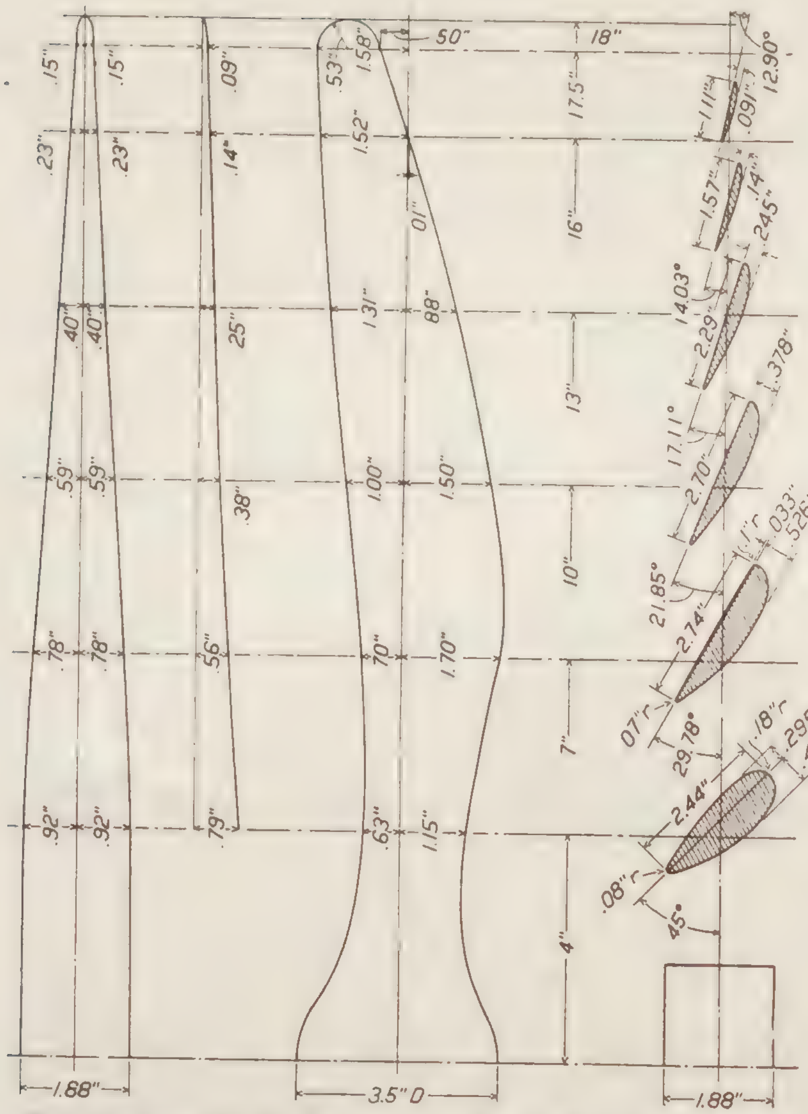


FIG. 13.—Propeller M. Diameter, 3 feet. Aspect ratio, 6.5 inches. maximum blade width, 2.77 inches. Pitch, 25.2 inches. Pitch ratio, 0.7. Camber ratio, minimum

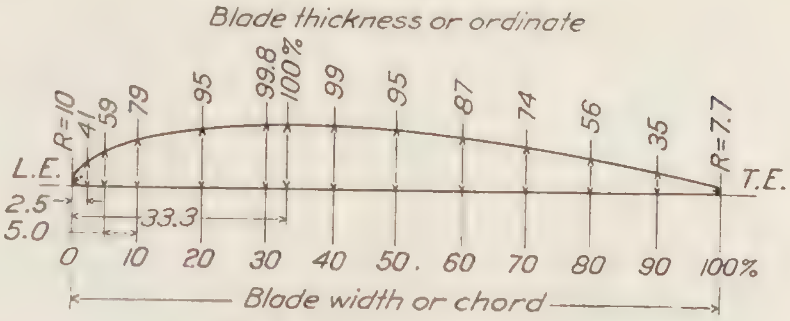


FIG. 14.—Standard blade section

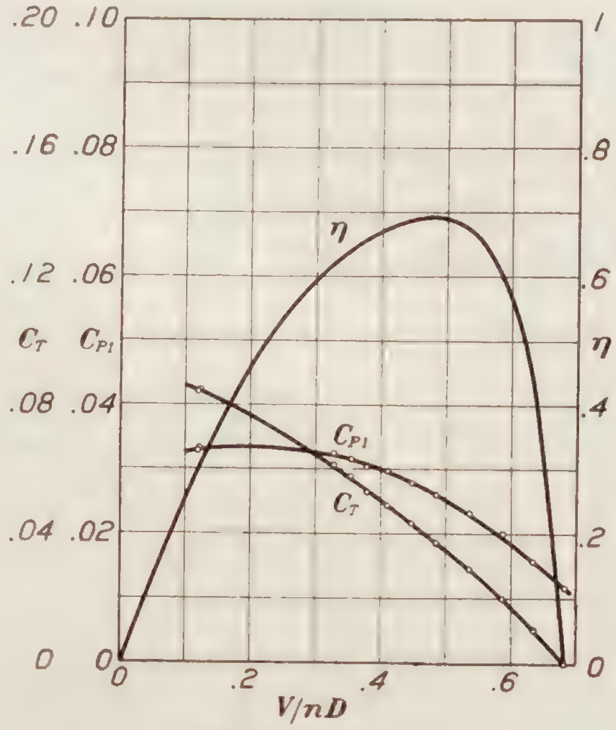


FIG. 15.—Propeller A

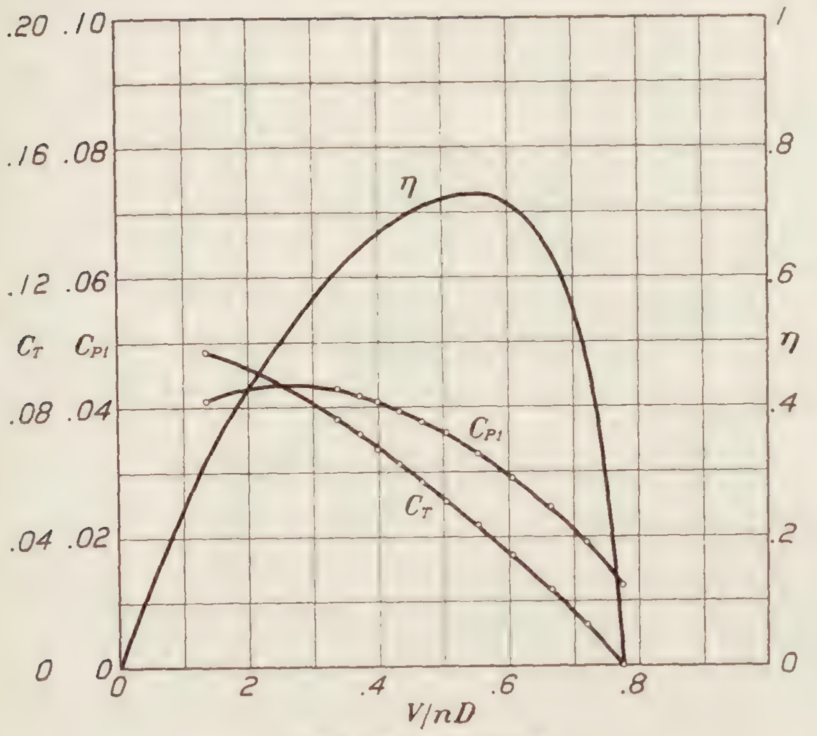


FIG. 16.—Propeller B

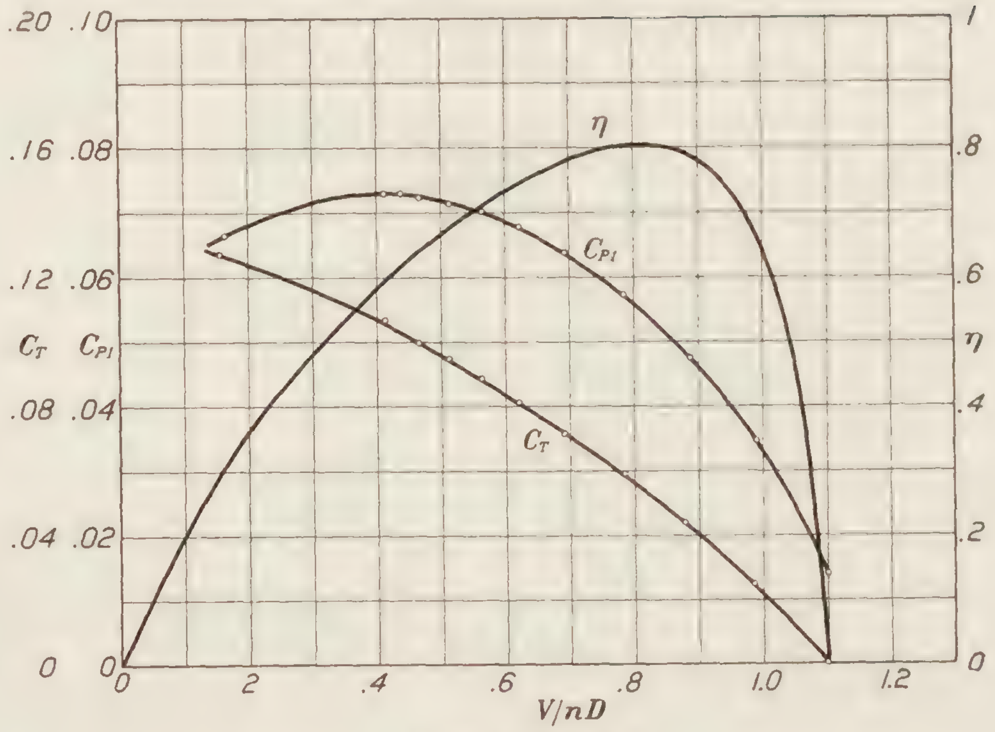


FIG. 19.—Propeller E

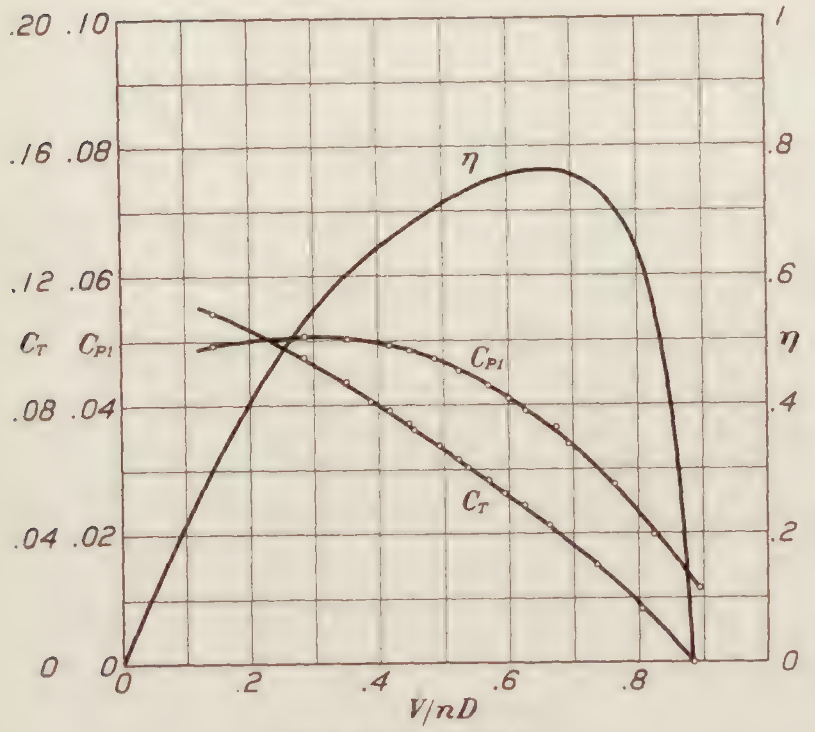


FIG. 17.—Propeller C

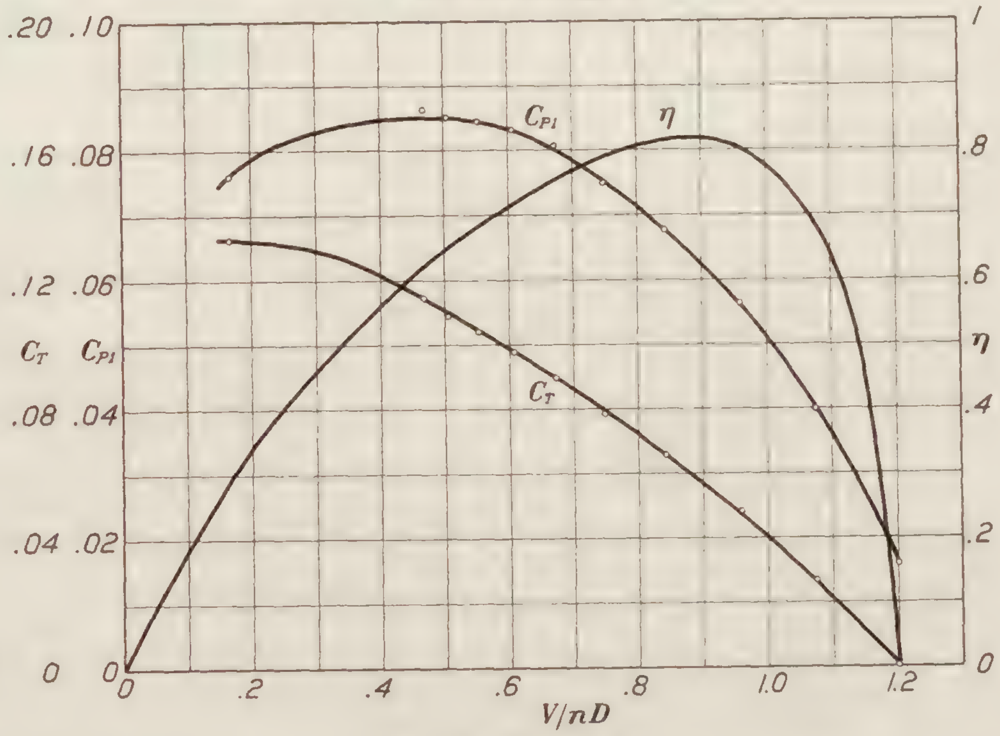


FIG. 20.—Propeller F

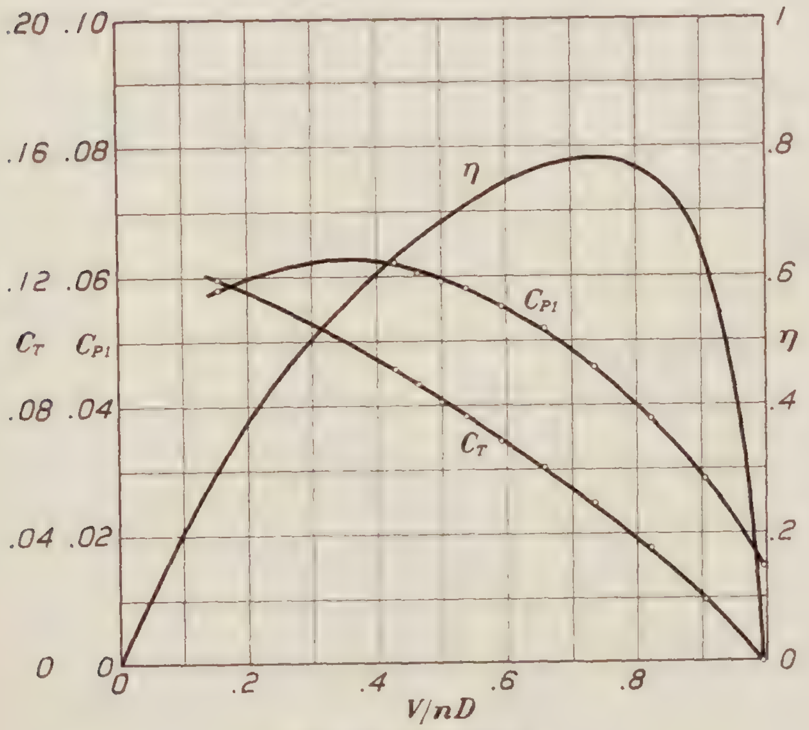


FIG. 18.—Propeller D

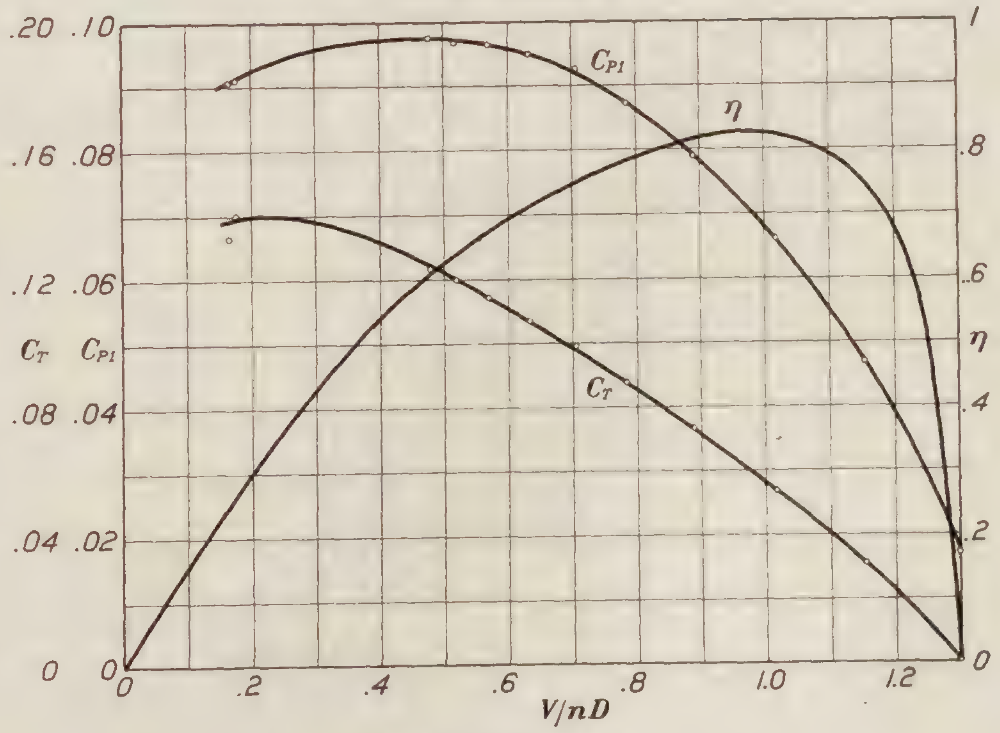


FIG. 21.—Propeller G

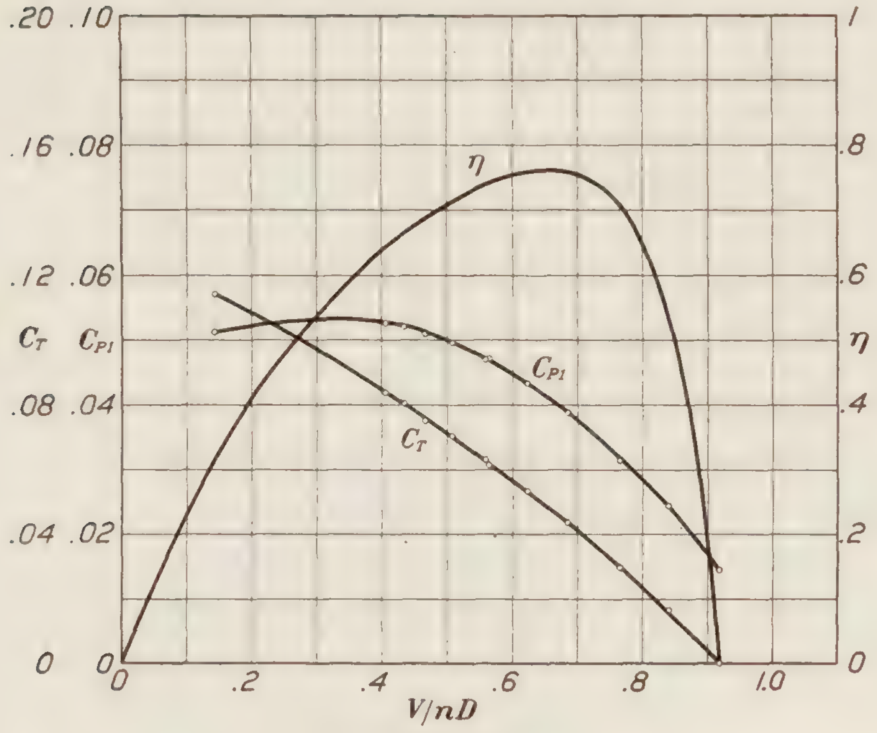


FIG. 22.—Propeller H

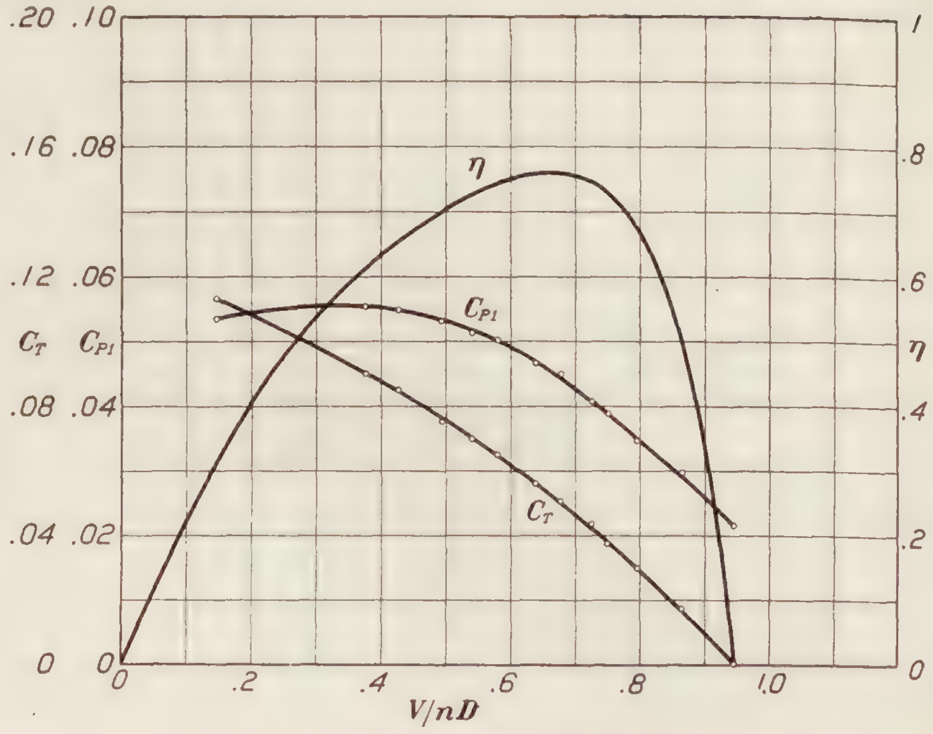


FIG. 23.—Propeller I

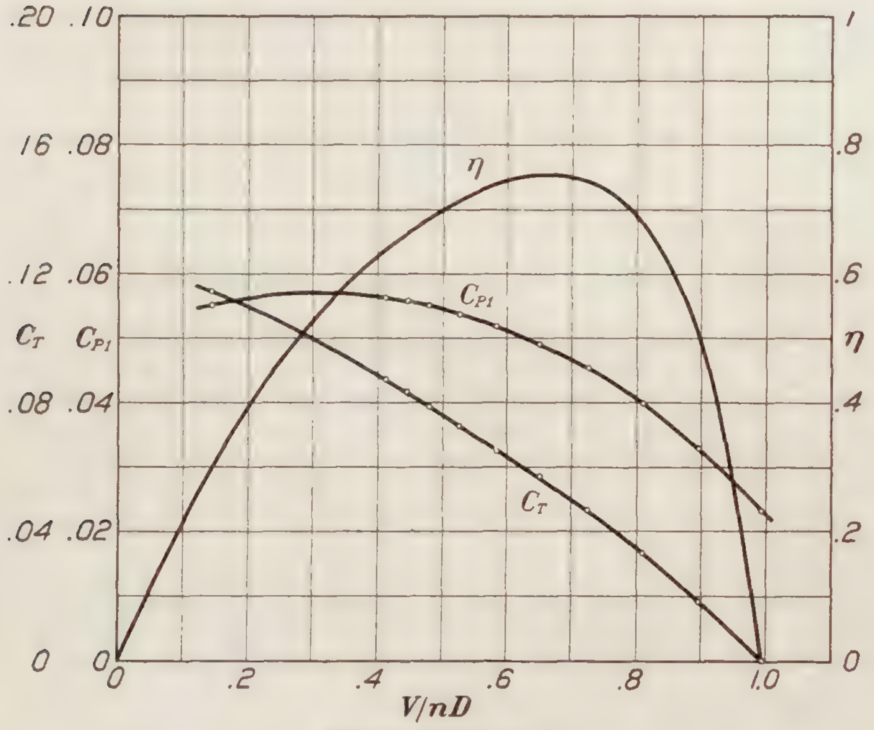


FIG. 24.—Propeller J

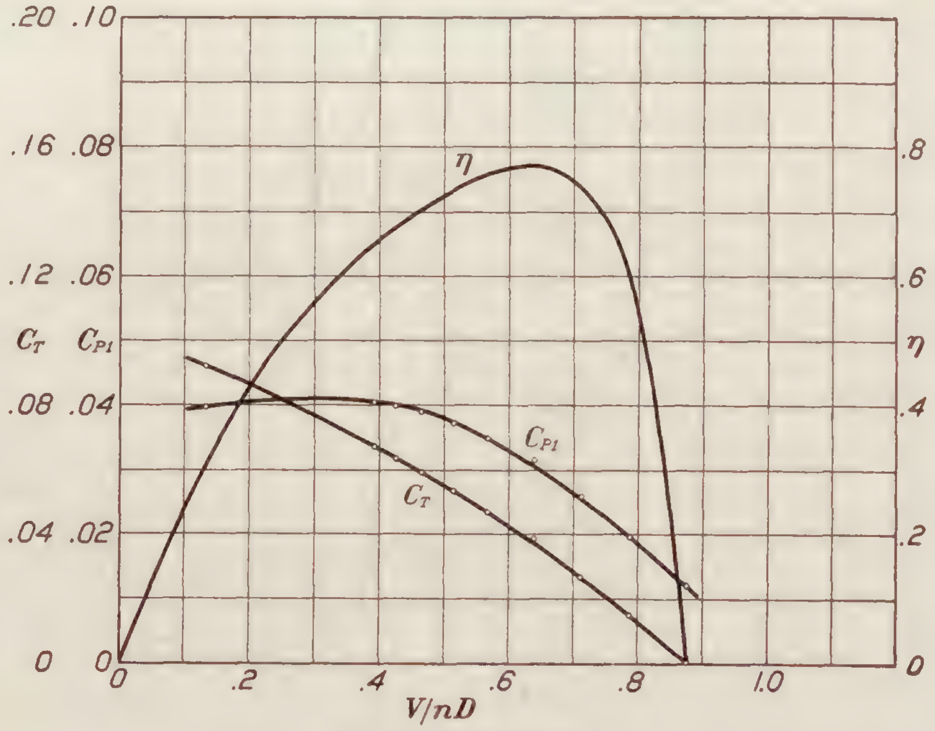


FIG. 25.—Propeller K

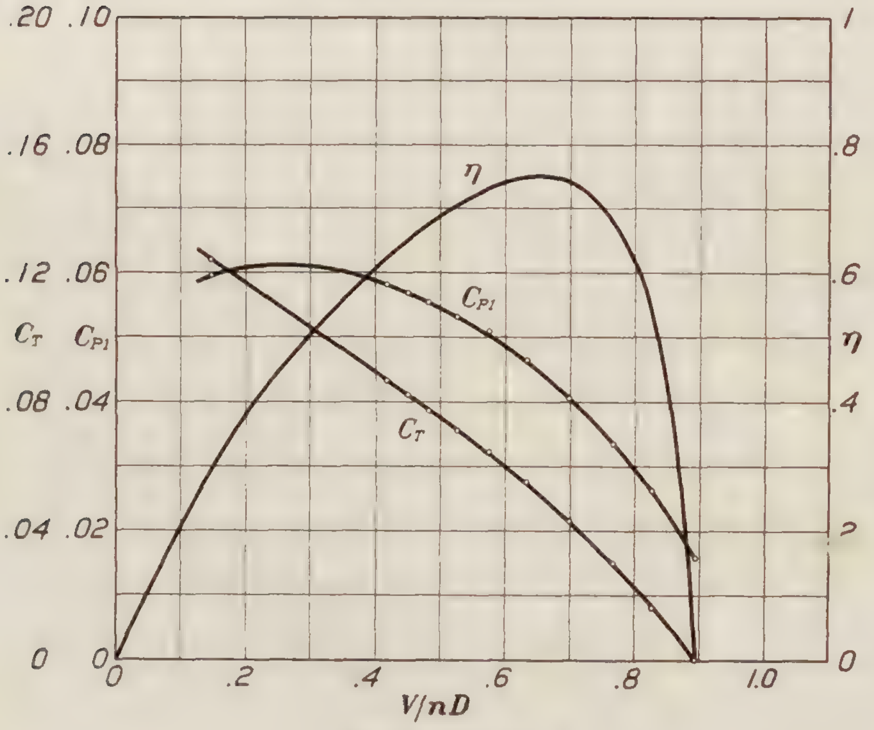


FIG. 26.—Propeller L

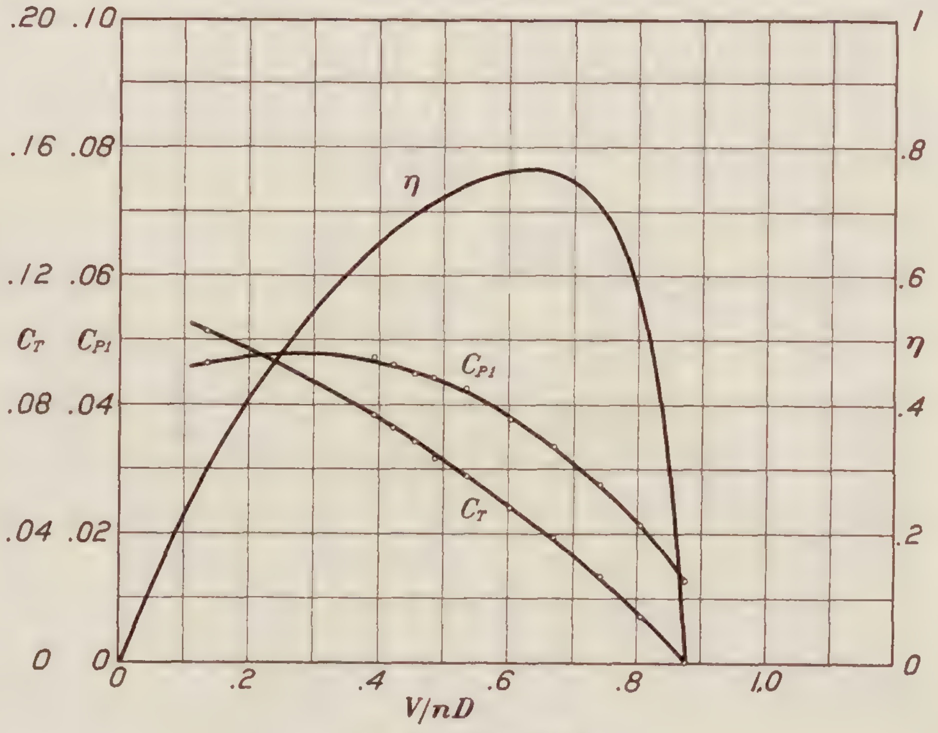


FIG. 27.—Propeller M

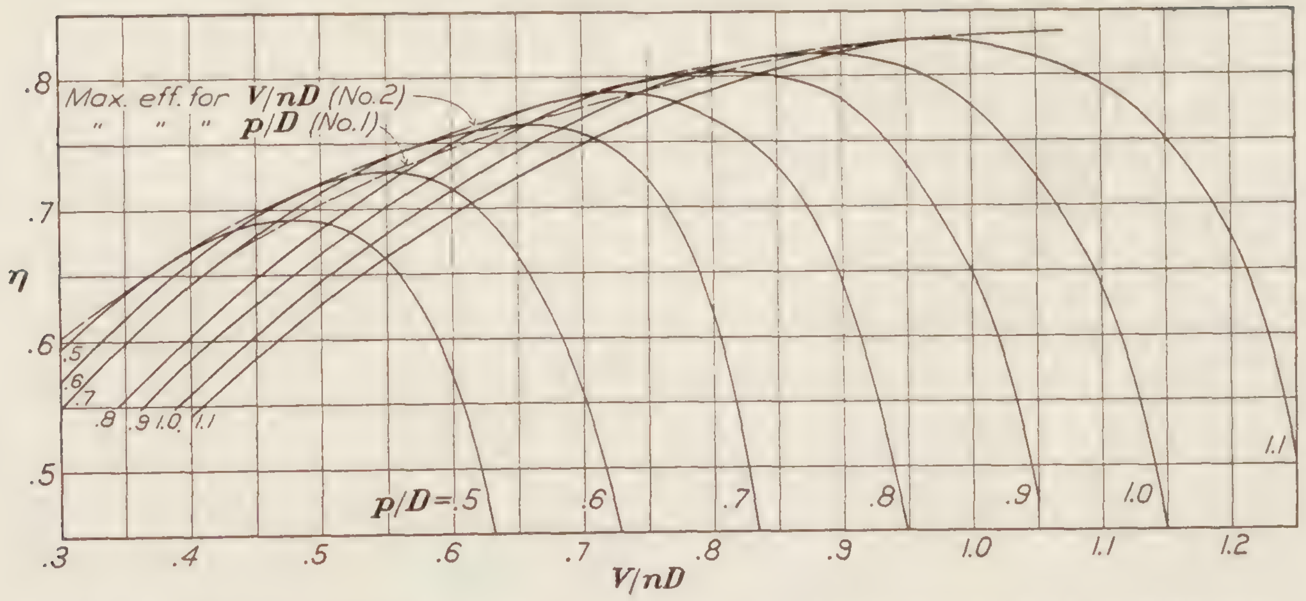


FIG. 28.—Propeller efficiencies for various P/D ratios and V/nD. Based on minimum camber and aspect ratio 6

REPORT No. 238

THE EFFECT OF FLIGHT PATH INCLINATION ON AIRPLANE VELOCITY

By WALTER S. DIEHL
Bureau of Aeronautics

REPORT No. 238

THE EFFECT OF FLIGHT PATH INCLINATION ON AIRPLANE VELOCITY

By Walter S. Diehl

SUMMARY

This report was prepared at the request of the National Advisory Committee for Aeronautics in order to supply a systematic study of the relations between the flight velocity V and its horizontal component V_H, in power glides. Curves of V and V_H plotted against the inclination of the flight path θ are given, together with curves which show the maximum values of V_H and the corresponding values of θ. Curves are also given showing the effect of small departures from the horizontal in high speed performance testing.

INTRODUCTION

While it is obvious that the speed of an airplane must be greater along a downwardly inclined flight path than along a horizontal flight path, there has not been in the past any great necessity for a systematic study of the relations involved, but in view of the probable interest which such a systematic solution would now hold, for pilots in particular, it has been undertaken.

The extent of previous calculations along this line appear to have been limited to the determination of the diving speed, a problem not considered in this study since it has been very well treated elsewhere. For example, see British Advisory Committee for Aeronautics, R. & M. No. 492 (Vol. II, 1917–18).

Owing to the nature of the variables, particularly the thrust, no strictly exact solution can be obtained for the relation between the angle of the flight path and the flight speed. The results are sufficiently exact for all practical purposes, however. Such inaccuracy as might be introduced by the assumption as to variation of thrust with speed would not be large except when the velocity was very large or very small.

In this report the phrase "Horizontal flight" means flight at constant altitude, in accordance with common usage.

THE EFFECT OF INCLINATION OF THE FLIGHT PATH ON HORIZONTAL VELOCITY

The forces acting on an airplane which is flying with full power along a path inclined $\theta°$ to the horizontal are the thrust T, the drag D, the lift L, and the weight W. Let it be assumed that

(1) The drag varies as the square of the velocity, i. e., $D=KV^2$.

(2) The thrust varies linearly with velocity and acts along the flight path.

Resolving the forces along the flight path gives $T-W\sin\theta=D=KV^2$ (1)

θ being considered positive for an upward inclination.

Consider an average airplane in horizontal flight at the maximum speed V_m. If the flight speed be increased the engine will speed up and deliver slightly more power, but since the increase in N is less rapid than the increase in V there will be an increase in V/ND and a decrease in the propeller efficiency η. The relation between thrust and speed may be conveniently studied by means of the coefficient $C_4=\frac{2\pi Q}{\rho V^2 D^3}$. Figure 3 of National Advisory Committee for Aeronautics Technical Report No. 186 contains a plot which gives the values of C_4 for varying ratio p/D and V/ND, so that for any p/D a curve of C_4 vs. V/ND may be drawn. Q and V are the only variables in C_4, and since the variation of Q with N and with V may be estimated closely, the value of C_4, V/ND and N may be obtained for any assumed value of V.

A study of two propellers gives the following results:

$\frac{V}{V_m}$		1.00	1.20	1.40	1.60	1.80	2.00
$\frac{p}{D}=0.5$	$\frac{N}{N_0}$	1.00	1.06	1.14	1.22	1.30	1.39
	$\frac{T}{T_0}$	1.00	.85	.71	.54	.35	.14
$\frac{p}{D}=1.0$	$\frac{N}{N_0}$	1.00	1.10	1.21	1.32	1.43	1.54
	$\frac{T}{T_0}$	1.00	.89	.78	.66	.54	.42

The values of T/T_0 plotted against V/V_m lie on or near two straight lines, which allows T to be expressed in terms of V by a simple linear relation.

When $V=2V_m$, T may be between zero and $T_0/2$ depending upon the propeller and engine characteristics, the average value probably being nearer to zero than to $T_0/2$.

Consequently

$$T=T_0-a(V-V_m)$$

and

$$T=\frac{T_0}{2} \text{ when } V=2V_m$$

therefore

$$a=\frac{T_0}{V_m}$$

and

$$T=2T_0-\frac{T_0V}{V_m} \tag{2}$$

Substituting Equation (2) in (1) gives

$$V^2=\frac{2T_0}{K}-\frac{T_0V}{KV_m}-\frac{W}{K}\sin\theta$$

or, since

$$T_0=KV_m^2 \text{ and } \frac{W}{T_0}=\left(\frac{L}{D}\right)_0$$

$$V^2=2V_m^2-VV_m-\left(\frac{L}{D}\right)_0 V_m^2\sin\theta \tag{3}$$

from which

$$V=V_m\left[-\frac{1}{2}+\sqrt{2.25-\left(\frac{L}{D}\right)_0\sin\theta}\right] \tag{4}$$

V is the velocity along the flight path which is inclined at the angle θ to the horizontal. The horizontal component of V is

$$V_H=V_m\left[-\frac{1}{2}+\sqrt{2.25-\left(\frac{L}{D}\right)_0\sin\theta}\right]\cos\theta \tag{5}$$

If the assumption be made that $T=T_0/2$ when $V=2V_m$, Equations (4) and (5) become

$$V=V_m\left[-\frac{1}{4}+\sqrt{1.5625-\left(\frac{L}{D}\right)_0\sin\theta}\right] \tag{4a}$$

and

$$V_H=V_m\left[-\frac{1}{4}+\sqrt{1.5625-\left(\frac{L}{D}\right)_0\sin\theta}\right]\cos\theta \tag{5a}$$

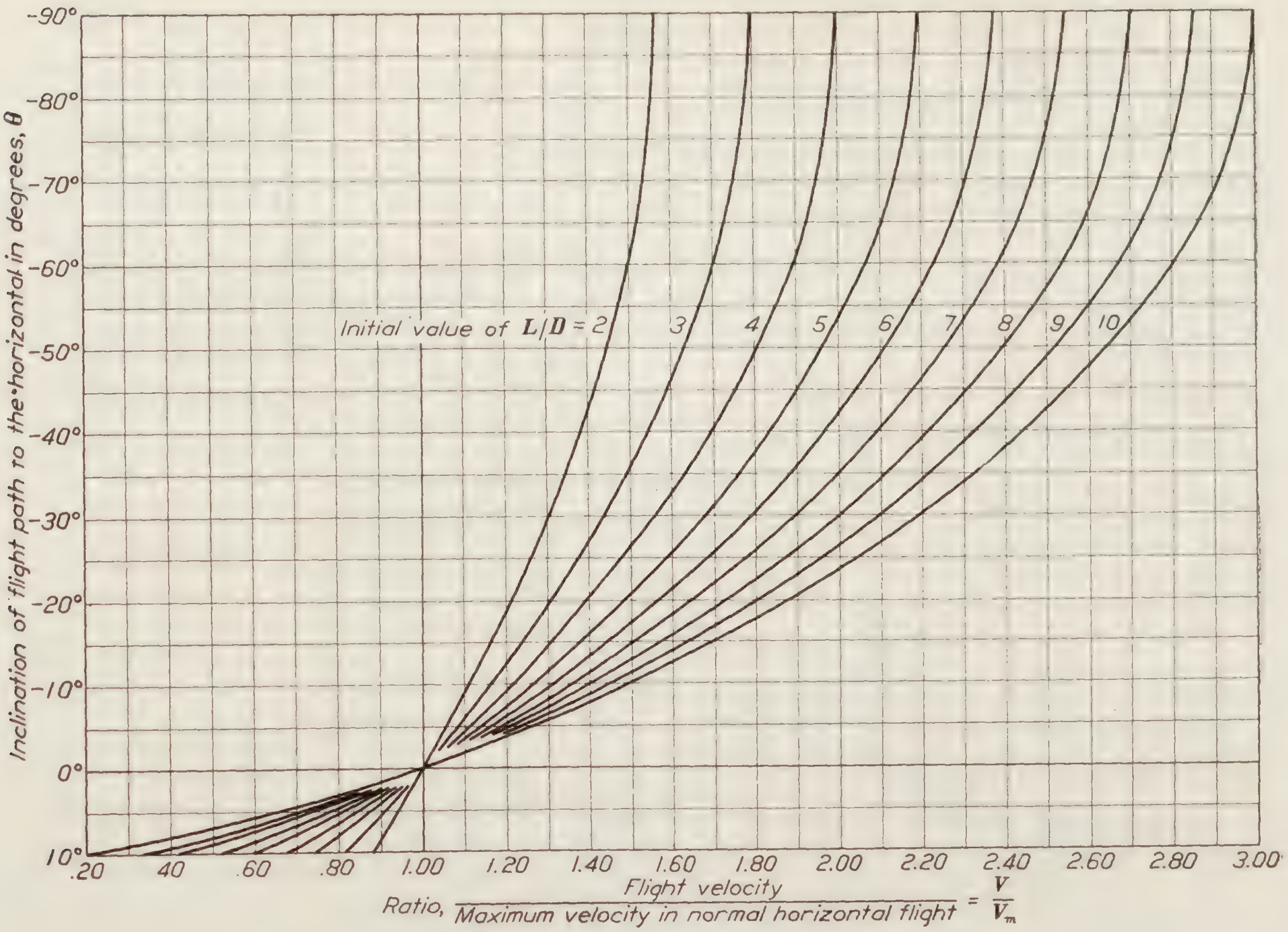


FIG. 1.—Effect of inclination of flight path on flight velocity.
Note: θ is negative when the flight path is inclined downward. (As in a glide)
$T=0$ when $V=2\,V_m$

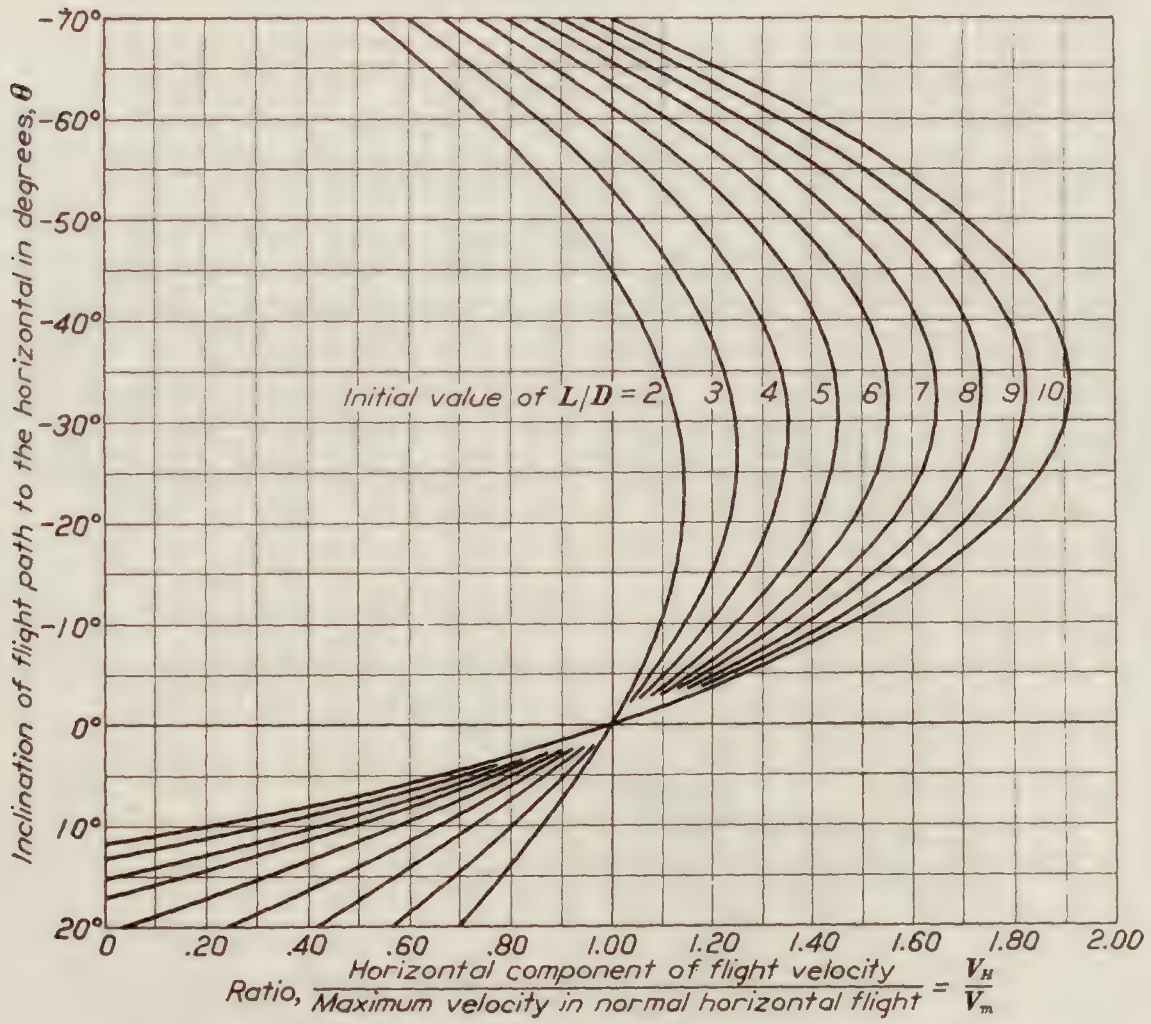


FIG. 2.—The effect of inclination of flight path on the horizontal component of flight velocity.
$T=0$ when $V=2\,V_m$

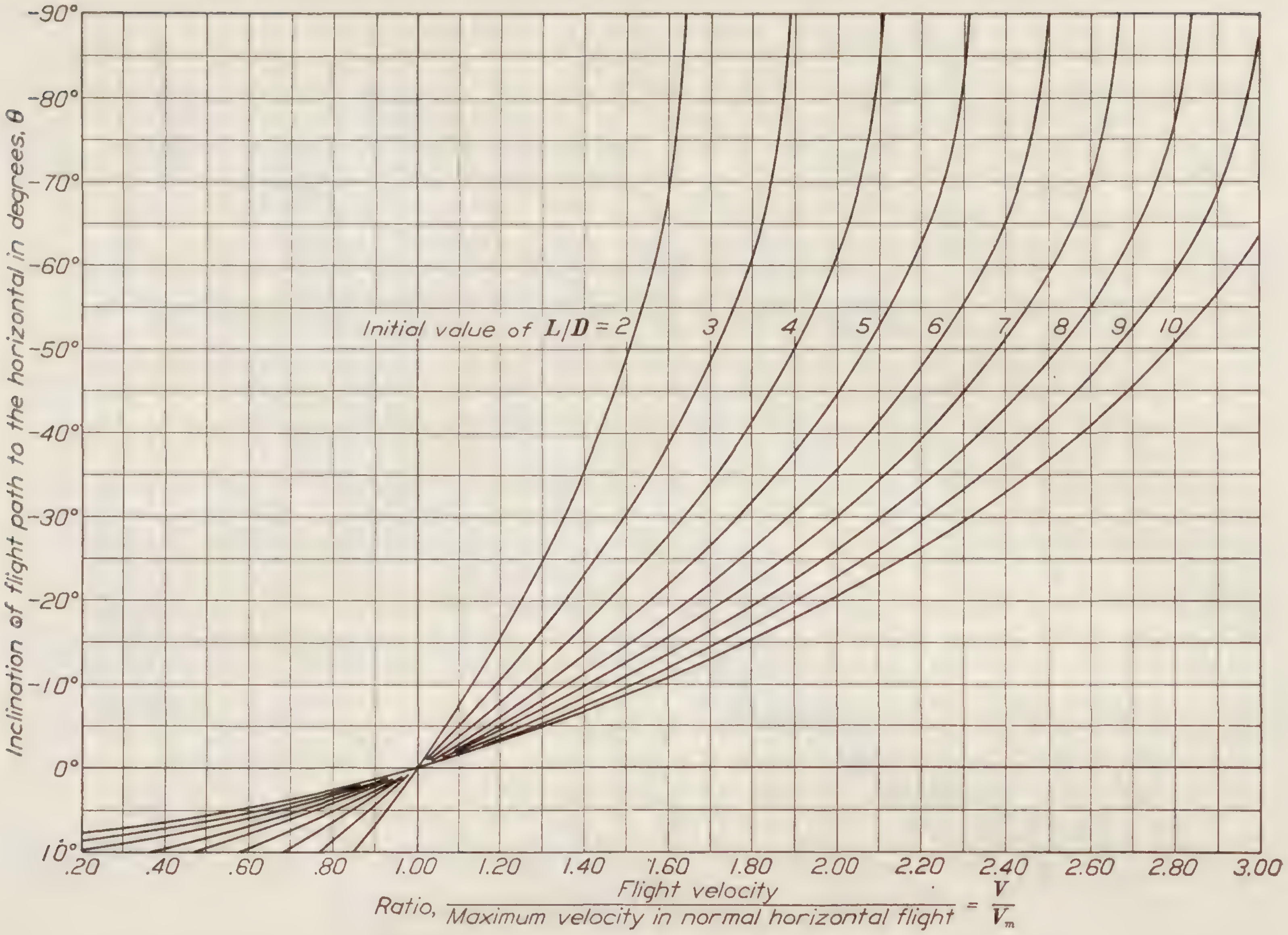


FIG. 3.—Effect of inclination of flight path on flight velocity.
Note: θ is negative when the flight path is inclined downward. (As in a glide)
$T=\frac{T_0}{2}$ when $V=2V_m$

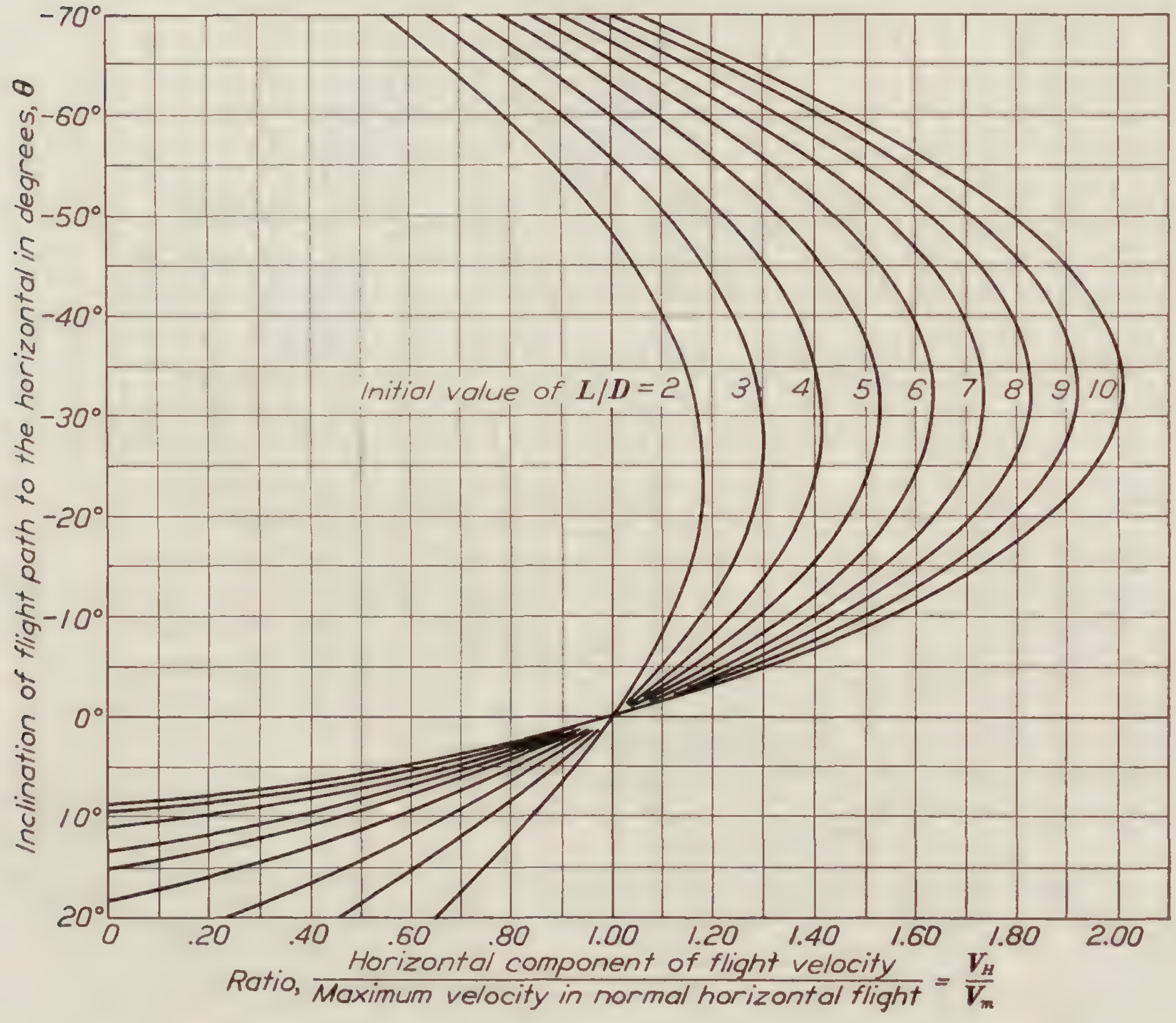


FIG. 4.—The effect of inclination of flight path on the horizontal component of flight velocity
$T=\frac{T_0}{2}$ when $V=2V_m$

INCREASE IN HORIZONTAL VELOCITY DUE TO DOWNWARD INCLINATION OF THE FLIGHT PATH

When an airplane flies with full power along a flight path which is inclined at $\theta°$ downward from the horizontal, the component of the weight ($L/D \sin \theta$) in Equation (5) is positive and increases the velocity along the flight path. An inspection of Equation (5) shows that the horizontal component of the flight velocity first increases, reaches a maximum value, and then decreases as θ is increased.

Tables I, II, III, and IV contain values of flight velocity and the ratio of the horizontal component of the flight velocity to the maximum velocity in sustained horizontal flight as calculated from Equations (4), (4a), (5), and (5a) for various values of $(L/D)_0$ and θ. These values are plotted on Figures 1, 2, 3, and 4.

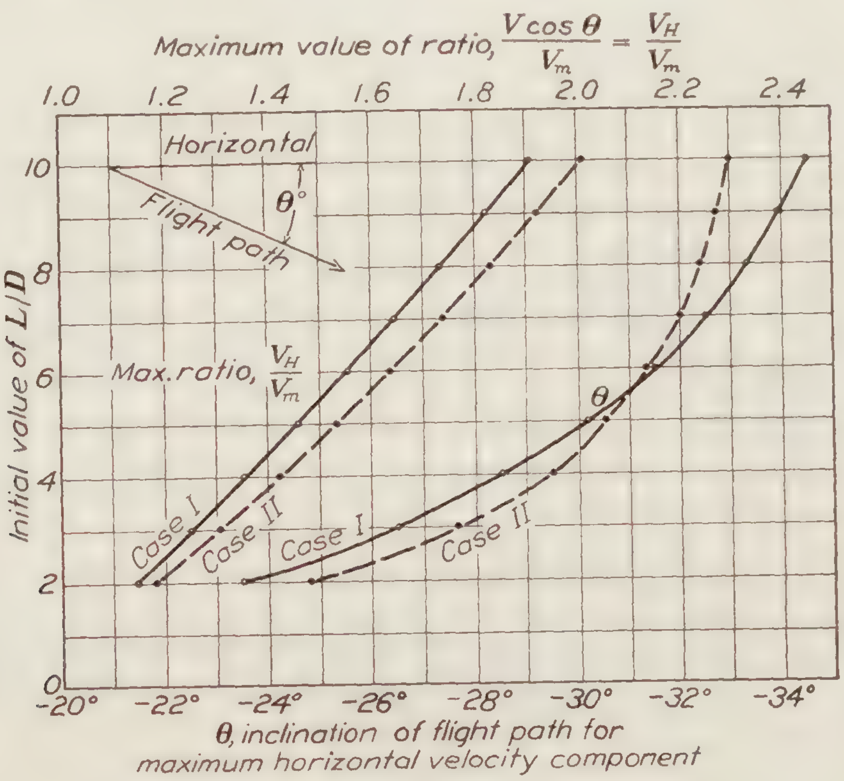


FIG. 5.

A study of Figures 2 and 4 discloses several interesting and instructive facts. For example, the maximum increase in effective horizontal velocity which may be obtained by flying along an inclined flight path is considerably greater than might be expected, since it is of the order of 40 per cent for the average airplane. It is also surprising to note that this maximum increase occurs for values of θ of the order of $-30°$. Equation (5) does not readily lend itself to the analytical calculation of the value of θ giving the maximum ratio V_H/V_m. These have therefore been obtained graphically from large-scale plots of Figures 2 and 4 and the values so obtained are given in Table V and plotted on Figure 5.

Figures 2 and 4 also show that for the average airplane θ must be of the order of $-60°$ before the horizontal component of the flight velocity becomes less than the maximum velocity which can be sustained in horizontal flight.

EFFECT OF A SLIGHT DEVIATION FROM A HORIZONTAL FLIGHT PATH

When the term $[(L/D)_0 \sin \theta]$ is less than 0.100 Equations (5) and (5a) may be written in the form

$$\frac{V_H}{V_m} = 1.000 - K\left(\frac{L}{D}\right)_0 \sin \theta$$

or since θ is small

$$\frac{V_H}{V_m} = 1.000 - K\left(\frac{L}{D}\right)_0 \frac{h}{l} \tag{6}$$

Where h is the altitude lost or gained in the distance l, and K is a constant depending on the assumed variation of thrust with speed. For $T = 0$ when $V = 2V_m$ as in Equation (5) $K = 0.333$.

For $T=T_0/2$ when $V=2V_m$ as in Equation (5a), $K=0.400$. h is negative if altitude is lost and positive if altitude is gained.

Figure 6 is a working diagram based on Equation (6) and the assumption that $T=0$ when $V=2V_m$. This diagram shows how the high speed is affected by a failure to maintain a true horizontal flight path during high-speed tests. Since the value of (L/D) at maximum speed is approximately 4 for the average airplane, a change of 40 feet in altitude per mile flown will change the maximum speed 1 per cent.

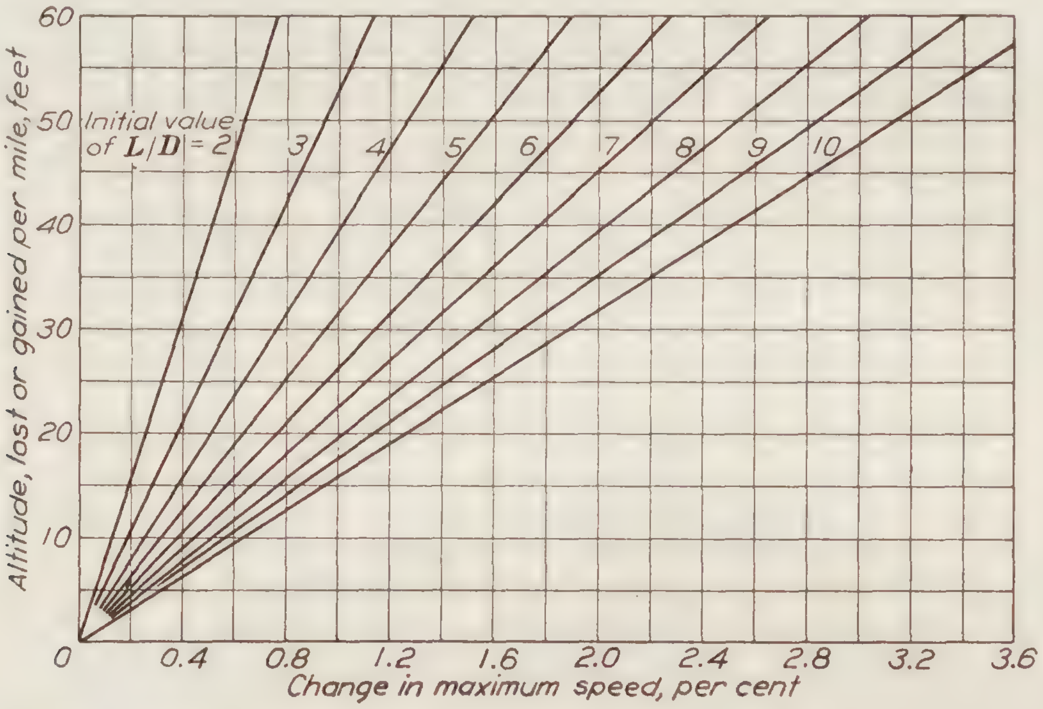


FIG. 6.—Effect of a slight inclination of the flight path on the maximum speed of airplanes.

The value of (L/D) at high speed may readily be determined for any airplane for which the maximum horizontal velocity V_m, brake horsepower (B.HP.), propeller efficiency η, and weight W are known. From the common power equation

$$D=\frac{375\ \eta\ \mathrm{B.HP}}{V_m}$$

V_m being in M. P. H. and D in lb.
Since $W=L$

$$\frac{L}{D}=\frac{W}{D}=\frac{WV_m}{375\eta\ \mathrm{B.HP}}=\frac{V_m}{375\eta}\left(\frac{W}{\mathrm{B.HP}}\right) \tag{7}$$

Table VI contains calculations for the value of L/D at maximum speed for a number of typical airplanes. This value varies from 3.5 to 6.0. It has no direct relation to the maximum value of (L/D) or to the "fineness" of the design.

APPLICATIONS

This study was originally intended to show what increase in maximum horizontal velocity, as represented by the horizontal component of the flight velocity, could be obtained in an emergency, such as the landing of a slow airplane in a high wind. However, the data has been prepared and presented in such form as to make available information on a number of items of interest to pilots, as follows:

(1) Variation of flight velocity with inclination of flight path. See Tables I and III and Figures 1 and 3.

(2) Variation of effective horizontal velocity (i. e., horizontal component of flight velocity) with inclination of flight path. See Tables II and IV and Figures 2 and 4.

(3) Maximum effective horizontal velocity and angle of inclination of flight path which gives this maximum. See Figures 2, 4, and 5.

(4) Approximate value of the angle of inclination of the flight path at which horizontal component of the flight velocity becomes equal to the maximum velocity in horizontal flight. See Table V and Figures 2, 4, and 5.

(5) Effect of a small departure from a horizontal flight path (of particular interest to test pilots). See Figure 6.

CONCLUSIONS

It has been shown that for an average airplane having, for example, $L/D=4.5$ at high speed, the maximum value of the horizontal component of the flight velocity in a power glide, becomes 40 per cent greater than the maximum velocity in horizontal flight. This maximum value occurs when the flight path is about 30° to the horizontal. It has also been shown that the flight path must be inclined downward about 60° from the horizontal before the horizontal component of the flight velocity becomes less than the maximum velocity in horizontal flight.

The necessity for maintaining a strictly horizontal flight path in performance testing is clearly brought out by Figure 6, which shows that for the average airplane a loss of 40 feet in altitude per mile flown is sufficient to increase the maximum speed 1 per cent.

A few words of caution seem desirable at this time. Owing to the uncertainty of the thrust, the calculations made in this study should be considered as approximations only. There is ample reason to believe, however, that the effect of a power glide is substantially as indicated except at very high flight velocities.

TABLE I

VARIATION OF FLIGHT VELOCITY WITH INCLINATION OF FLIGHT PATH

$T=O$ when $V=2V_m$

$$\frac{V}{V_m}=\left[-\frac{1}{2}+\sqrt{2.25-\left(\frac{L}{D}\right)_0\sin\theta}\right]$$

$\left(\frac{L}{D}\right)_0=$	2	3	4	5	6	7	8	9	10
Inclination of flight path θ					$\frac{V}{V_m}$				
+20	0.752	0.606	0.439	0.235	---------	---------	---------	---------	---------
+15	.816	.714	.602	.478	0.335	0.162	---------	---------	---------
+10	.880	.815	.747	.675	.599	.517	0.428	0.329	0.217
+5	.940	.910	.878	.847	.813	.780	.746	.710	.673
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
−5	1.057	1.085	1.112	1.139	1.165	1.191	1.217	1.242	1.267
−10	1.111	1.165	1.216	1.266	1.315	1.362	1.408	1.452	1.496
−15	1.164	1.240	1.313	1.383	1.451	1.517	1.579	1.640	1.700
−20	1.213	1.310	1.402	1.490	1.574	1.655	1.733	1.810	1.882
−25	1.259	1.375	1.485	1.590	1.688	1.783	1.873	1.960	2.045
−30	1.303	1.437	1.562	1.680	1.792	1.898	2.000	2.098	2.192
−35	1.343	1.493	1.632	1.763	1.886	2.003	2.115	2.223	2.327
−40	1.380	1.546	1.696	1.838	1.972	2.098	2.220	2.333	2.447
−50	1.445	1.632	1.806	1.966	2.116	2.260	2.396	2.524	2.648
−60	1.496	1.703	1.892	2.066	2.230	2.383	2.530	2.670	2.803
−70	1.532	1.752	1.951	2.135	2.310	2.472	2.626	2.773	2.913
−90	1.562	1.792	2.000	2.193	2.373	2.542	2.703	2.854	3.000

TABLE II

VARIATION IN HORIZONTAL COMPONENT OF FLIGHT VELOCITY WITH INCLINATION OF FLIGHT PATH

$T=0$ when $V=2V_m$

$$\frac{V_H}{V_m}=\left[-\frac{1}{2}+\sqrt{2.25-\left(\frac{L}{D}\right)_0 \sin\theta}\right]\cos\theta$$

$\left(\frac{L}{D}\right)_0=$	2	3	4	5	6	7	8	9	10
Inclination of flight path θ	$\frac{V_H}{V_m}$								
+20	0.707	0.569	0.413	0.221	--------	--------	--------	--------	--------
+15	.779	.690	.581	.462	0.324	0.157	--------	--------	--------
+10	.867	.803	.736	.665	.590	.509	0.422	0.324	0.214
+5	.937	.907	.875	.844	.810	.777	.743	.707	.670
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
−5	1.053	1.081	1.108	1.135	1.161	1.187	1.213	1.237	1.263
−10	1.094	1.148	1.198	1.247	1.296	1.342	1.387	1.430	1.474
−15	1.125	1.198	1.268	1.337	1.402	1.466	1.526	1.584	1.642
−20	1.140	1.232	1.318	1.401	1.480	1.556	1.630	1.702	1.769
−25	1.142	1.247	1.346	1.442	1.530	1.616	1.688	1.777	1.855
−30	1.128	1.245	1.352	1.455	1.552	1.644	1.732	1.818	1.898
−35	1.101	1.223	1.337	1.445	1.545	1.642	1.733	1.822	1.907
−40	1.057	1.185	1.299	1.409	1.511	1.608	1.701	1.787	1.875
−50	.929	1.049	1.161	1.264	1.361	1.453	1.540	1.624	1.703
−60	.748	.852	.946	1.033	1.115	1.192	1.265	1.335	1.402
−70	.524	.599	.667	.730	.790	.845	.898	.948	.996
−90	.000	.000	.000	.000	.000	.000	.000	.000	.000

TABLE III

VARIATION OF FLIGHT VELOCITY WITH INCLINATION OF FLIGHT PATH

$T=\frac{T_0}{2}$ when $V=2V_m$

$$\frac{V}{V_m}=\left[-\frac{1}{4}+\sqrt{1.5625-\left(\frac{L}{D}\right)_0 \sin\theta}\right]$$

$\left(\frac{L}{D}\right)_0=$	2	3	4	5	6	7	8	9	10
Inclination of flight path θ	$\frac{V}{V_m}$								
+20	0.687	0.482	0.191	--------	--------	--------	--------	--------	--------
+15	.772	.636	.476	0.268	0.042	--------	--------	--------	--------
+10	.852	.770	.682	.583	.472	0.389	0.167	--------	--------
+5	.928	.890	.851	.811	.769	.726	.680	0.632	0.581
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
−5	1.067	1.100	1.132	1.163	1.194	1.223	1.253	1.282	1.310
−10	1.131	1.194	1.252	1.309	1.363	1.416	1.467	1.517	1.565
−15	1.193	1.279	1.362	1.440	1.515	1.588	1.655	1.723	1.788
−20	1.248	1.358	1.461	1.558	1.652	1.738	1.822	1.904	1.982
−25	1.302	1.432	1.554	1.666	1.773	1.877	1.972	2.066	2.157
−30	1.351	1.500	1.637	1.767	1.887	2.000	2.108	2.213	2.312
−35	1.396	1.562	1.713	1.855	1.987	2.112	2.230	2.343	2.452
−40	1.438	1.618	1.783	1.936	2.078	2.213	2.340	2.461	2.577
−50	1.509	1.715	1.901	2.072	2.232	2.382	2.524	2.660	2.788
−60	1.565	1.796	1.993	2.177	2.350	2.512	2.664	2.810	2.950
−70	1.606	1.843	2.057	2.253	2.434	2.603	2.765	2.916	3.060
−90	1.638	1.887	2.110	2.323	2.500	2.667	2.842	3.000	3.150

TABLE IV

VARIATION IN HORIZONTAL COMPONENT OF FLIGHT VELOCITY WITH INCLINATION OF FLIGHT PATH

$$T=\frac{T_0}{2} \text{ when } V=2V_m$$

$$\frac{V_H}{V_m}=\left[-\frac{1}{4}+\sqrt{1.5625-\left(\frac{L}{D}\right)_0 \sin\theta}\,\right]\cos\theta$$

$\left(\frac{L}{D}\right)_0=$	2	3	4	5	6	7	8	9	10
Inclination of flight path θ	$\frac{V_H}{V_m}$								
+20	0.646	0.453	0.180	----------	----------	----------	----------	----------	----------
+15	.746	.614	.460	0.258	0.041	----------	----------	----------	----------
+10	.839	.758	.672	.574	.465	0.383	0.164	----------	----------
+5	.925	.886	.848	.808	.766	.723	.678	0.630	0.579
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
−5	1.063	1.096	1.128	1.158	1.190	1.218	1.248	1.277	1.305
−10	1.115	1.176	1.233	1.289	1.343	1.396	1.445	1.496	1.543
−15	1.152	1.235	1.315	1.392	1.463	1.535	1.599	1.665	1.728
−20	1.174	1.277	1.373	1.465	1.552	1.635	1.713	1.790	1.863
−25	1.180	1.298	1.408	1.510	1.606	1.700	1.786	1.872	1.954
−30	1.170	1.298	1.418	1.531	1.635	1.732	1.826	1.917	2.003
−35	1.143	1.280	1.403	1.518	1.628	1.729	1.826	1.918	2.008
−40	1.102	1.240	1.366	1.483	1.592	1.695	1.793	1.885	1.974
−50	.971	1.103	1.223	1.333	1.436	1.532	1.623	1.711	1.793
−60	.782	.898	.997	1.088	1.175	1.256	1.333	1.415	1.475
−70	.549	.630	.703	.771	.833	.891	.946	.997	1.046

TABLE V

MAXIMUM INCREASE IN HORIZONTAL VELOCITY AND CORRESPONDING INCLINATION OF FLIGHT PATH

$\left(\frac{L}{D}\right)_0$	Case I: $T=0$ when $V=2V_m$			Case II: $T=\frac{T_0}{2}$ when $V=2V_m$		
	Maximum value of $\frac{V_H}{V_m}$	Value of θ for maximum value of $\frac{V_H}{V_m}$	Approximate value of θ for $\frac{V_H}{V_m}=1.0$	Maximum value of $\frac{V_H}{V_m}$	Value of θ for maximum value of $\frac{V_H}{V_m}$	Approximate value of θ for $\frac{V_H}{V_m}=1.0$
2	1.143	23.5	44.8	1.180	24.8	48.3
3	1.248	26.5	53.0	1.302	27.6	55.6
4	1.353	28.5	57.7	1.418	29.5	59.9
5	1.455	30.2	61.1	1.532	30.5	63.1
6	1.553	31.5	63.6	1.636	31.3	65.4
7	1.646	32.5	65.6	1.737	32.0	67.3
8	1.736	33.3	67.3	1.832	32.4	68.7
9	1.823	33.9	68.7	1.925	32.7	69.9
10	1.907	34.5	69.8	2.012	33.0	70.7

V_H=horizontal component of flight velocity.

V_m=maximum velocity which can be sustained in horizontal flight.

TABLE VI

VALUE OF $\frac{L}{D}$ AT MAXIMUM SPEED

Airplane	Gross weight W lb.	Maximum speed V_m M. P. H.	B. HP.	Maximum propeller efficiency η_m	$\frac{L}{D}$ maximum speed
DH-4	4,300	124.0	420	0.75	4.5
VE-7	2,270	124.0	194	.77	5.0
SE-5	2,060	123.0	190	.77	4.6
MB-3	2,094	152.0	300	.80	3.5
MT	12,100	105.0	800	.76	5.6
JL-6 monoplane	3,600	111.0	240	.74	6.0
Sperry messenger	860	97.0	64	.78	4.5
Fokker D VII	2,460	151.0	350	.78	3.6
DT-2 seaplane	7,300	100.0	420	.71	6.5
TS-1 seaplane	2,125	122.0	208	.78	4.2
F5L boat	13,600	89.7	800	.68	6.0
R2C-1 land plane	2,300	248.0	500	.85	3.6

NOTE: $\frac{L}{D}$ at maximum speed must not be confused with the maximum value of $\frac{L}{D}$.

REPORT No. 239

POWER OUTPUT AND AIR REQUIREMENTS OF A TWO-STROKE CYCLE ENGINE FOR AERONAUTICAL USE

By C. R. PATON and CARLTON KEMPER
Langley Memorial Aeronautical Laboratory

REPORT No. 239

POWER OUTPUT AND AIR REQUIREMENTS OF A TWO-STROKE CYCLE ENGINE FOR AERONAUTICAL USE

By C. R. Paton and Carlton Kemper

SUMMARY

The investigation herein reported was undertaken by the National Advisory Committee for Aeronautics at its research laboratory, Langley Field, Va., in order to determine the pressure and amount of air necessary for satisfactory high-speed two-stroke cycle operation and thus permit the power requirements of the air pump or blower to be determined. Assembly and development of the apparatus and preliminary work in connection with the fuel-injection system were done under the direction of Mr. Robertson Matthews.

The object of this investigation was to determine the pressure and amount of air necessary for satisfactory scavenging and operation of a high-speed, two-stroke cycle engine for aeronautical use, a 5 by 7 inch single-cylinder Liberty test engine being adapted for the purpose. The fuel and scavenging system consisted of a fuel-injection pump and injection valve, used in conjunction with a separately driven Roots type blower. Tests were conducted at speeds of 1,000, 1,200, and 1,300 revolutions per minute, with air-supply pressures from 2 to 6 lb./sq. in. gauge, and results show, that 53 brake horsepower could be developed at 1,300 revolutions per minute, with a scavenging air pressure of 5.5 lb./sq. in., a specific air consumption of 9 lb./B.HP./hr., and a specific fuel consumption of 0.61 lb./B.HP./hr. Under these conditions 3 horsepower was required to supply the air, resulting in a net power output of 50 brake horsepower. A minimum specific air consumption of 8.4 lb./B.HP. was obtained at this speed with an air-supply pressure of approximately 3.5 lb./sq. in. when developing 41 brake horsepower. Chattering of cam-operated exhaust valves prevented higher speeds.

Based on power output and air requirement here obtained the two-stroke cycle engine would seem to be favorable for aeronautical use. No attempts were made to secure satisfactory operation at idling speeds.

INTRODUCTION

It has frequently been proposed to use engines operating on the two-stroke cycle for aircraft, because of the inherent possibilities of obtaining decreased weight per horsepower. In order, however, to operate economically at high speeds and high mean effective pressure, some auxiliary means of scavenging, that would tend to avoid loss of fuel with the exhaust, is necessary. Special attention has been recently directed toward the use of a compressor or blower to supply the necessary air for scavenging, as well as for combustion, in order to increase the power output.

To estimate the performance of such an engine, among other things the power required by the air pump or blower must be considered. This is dependent on the pressure and amount of air necessary for satisfactory scavenging. No adequate information was available concerning these requirements for high-speed two-stroke cycle engines.

Considerable research and development work had been done along these lines but most of it was applicable to engines operating at relatively low speeds. During the war, Doctor Junkers, in Germany, developed (Reference 1) a 500-horsepower, six-cylinder, valveless two-stroke cycle engine for aviation purposes having two opposed pistons per cylinder and using airless fuel injection, electric ignition, and a direct connected scavenging blower. Operation was reported to be satisfactory at 2,000 revolutions per minute. However, work on this engine was discontinued at the close of the war and no test results were available concerning its air requirements.

DESCRIPTION OF EQUIPMENT

ENGINE AND AIR SYSTEM

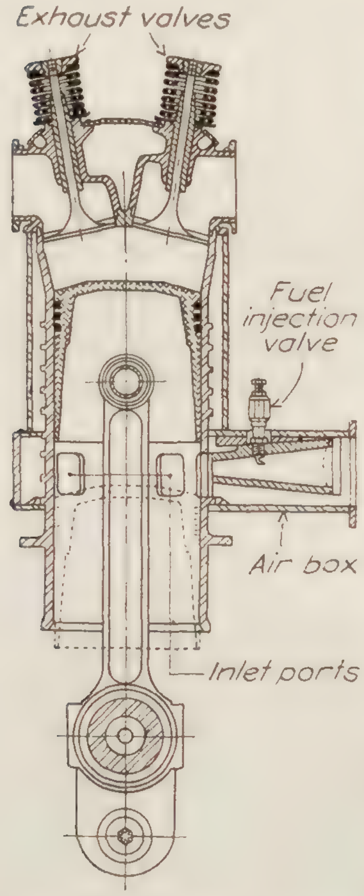
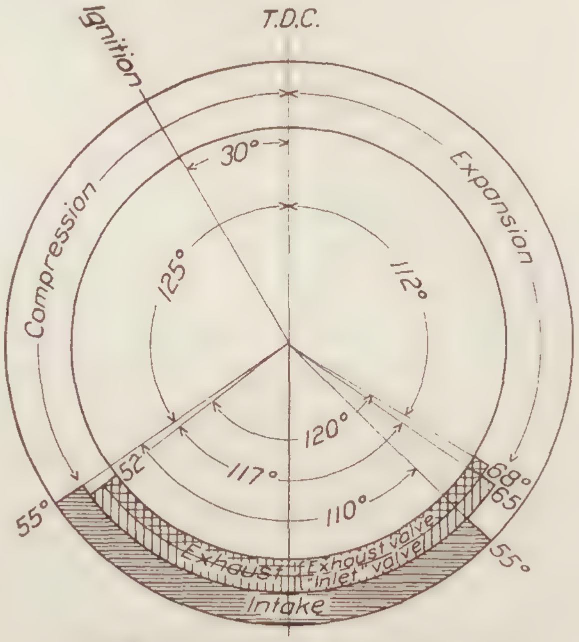


FIG. 1.—Two-stroke Liberty adaption, showing extent of jacket removed to accommodate inlet ports and air box, also amount standard piston overtravels inlet ports



"Inlet" valve used as exhaust valve

FIG. 2.—Two-stroke cycle valve timing

For the purpose of this investigation a single cylinder Liberty test engine, having a 5-inch bore and 7-inch stroke, was used. It was altered as necessary to permit its operation on the two-stroke cycle with domestic aviation gasoline as fuel and with the usual electric ignition. The standard Liberty cylinder was altered as shown in Figure 1, mounted on a single cylinder crank case and the engine connected to an electric cradle type dynamometer. Air was supplied at various pressures by a separately driven Roots blower and fuel was sprayed into the air, as it entered the cylinder, by a cam actuated fuel injection pump and spring loaded fuel injection valve. This airless fuel injection system, substituted for the usual carbureter, allowed the time of injection to be so delayed as to prevent the loss of fuel with the exhaust gases and scavenging air. As shown, inlet ports were provided in the cylinder wall which communicated with a box to which air was supplied under pressure by the blower. Both valves in the head were used for exhaust and were operated by a modified Liberty valve mechanism. Exhaust through valves in the head was adopted primarily to facilitate the necessary alterations to the Liberty cylinder, it being more difficult to provide suitably cooled exhaust ports at the base of the cylinder than to exhaust through the two valves in the head, where suitable cooling was already provided. Figure 2 shows a diagram of the timing of ports and valves. Scavenging air entered the cylinder as the piston uncovered the ports; the injection of fuel into the air being delayed to insure that the minimum amount would be carried out through the exhaust with the scavenging air.

The piston used was similar in form to the standard Liberty high compression type and gave an effective compression ratio, considering the reduction in effective stroke caused by the presence of the inlet ports, of 4.7 to 1. A

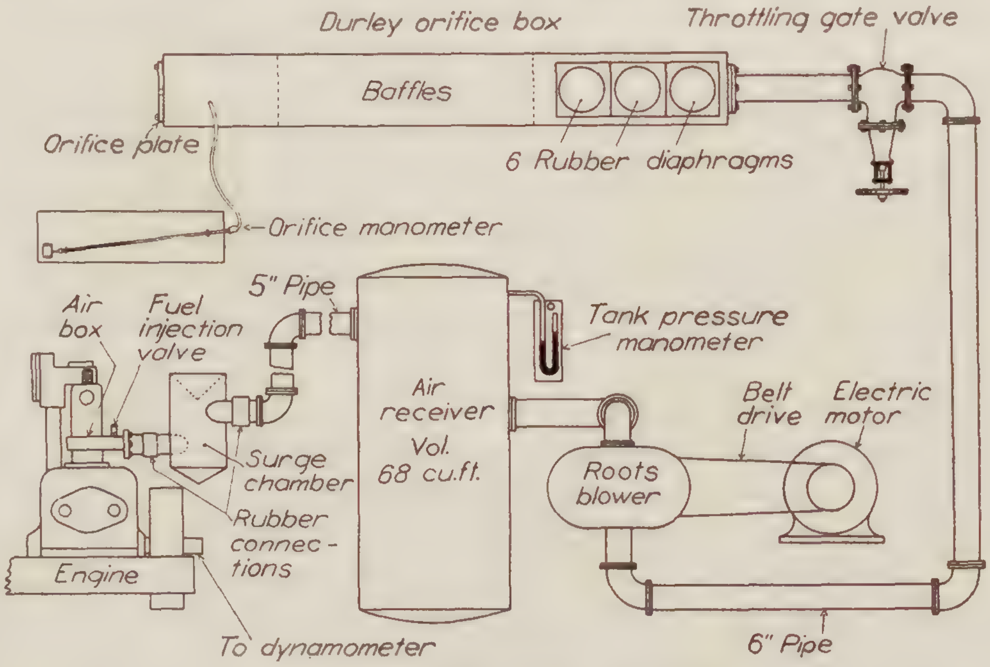


FIG. 3.—Diagrammatic sketch of air system

piston having a skirt sufficiently long to cover the ports with the piston at the top of the stroke could not readily be adapted; therefore the crank case was closed and subjected to approximately the same mean pressure as the air supplied to the engine.

A diagrammatic sketch of the apparatus used for measuring and supplying air under pressure is shown in Figure 3, a standard 2-inch Durley orifice (References 2 and 3) being used to determine the air consumption. Pressure fluctuations normally existing as a result of the operation of the blower and of the intermittent flow to the engine were reduced by a combination of a throttling valve, rubber diaphragms, large capacity receivers, and baffles so that this method should give fairly reliable results. A small surge chamber was placed as near the engine as possible to insure freedom from irregular operation due to surging in the air line.

FUEL SYSTEM

The fuel system comprised a primary gear pump, supplying fuel at a pressure of 70 lb./sq. in. to a cam-actuated plunger type injection pump, which in turn supplied fuel to a spring-loaded injection nozzle. The nozzle was arranged to spray the fuel into the air as it entered the engine cylinder, the spray being directed against the air stream. This location and arrangement of the nozzle was selected after trials which showed it to give the maximum power output.

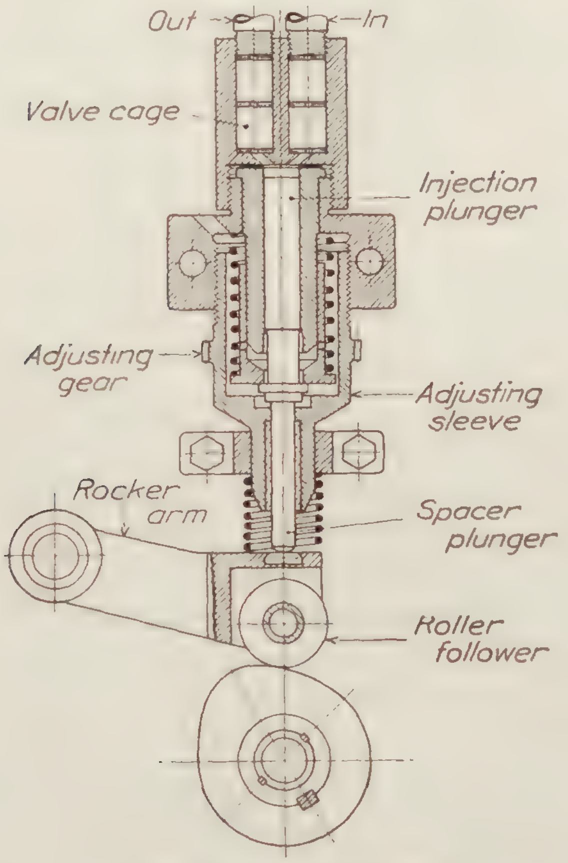


Fig. 4.—Fuel injection pump

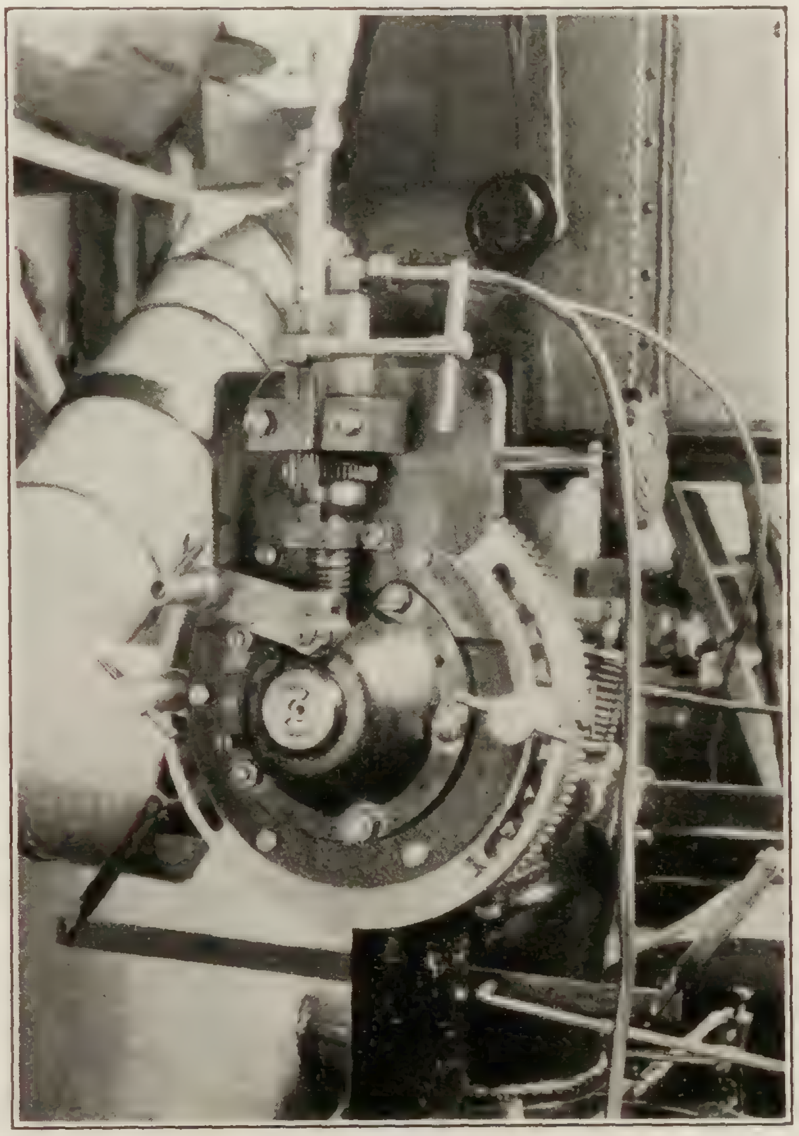


Fig. 5.—Fuel injection pump and timing mechanism

A sketch of the injection pump is shown in Figure 4. The cam operates the pump plunger by means of a rocker arm having a roller follower. A threaded adjusting sleeve operated by a gear and hand crank (fig. 5) limits the suction stroke of this plunger, thereby, controlling the quantity of fuel injected per cycle. The hub of this sleeve is graduated, permitting accurate adjustment of the pump stroke from zero to the maximum cam lift of 0.200 inch by increments of 0.005 inch. The best results were obtained with a plunger diameter of 0.53 inch; only approximately one-fourth of the available plunger stroke was required for the maximum power developed. The injection pump is mounted on a special timing head (shown in figs. 5 and 6). A convenient hand wheel operating a worm permits adjustment of the injection timing while the engine is operating.

A sketch of the fuel injection valve is shown in Figure 7. The needle valve has a lapped fit in the valve body and is lifted by the fuel pressure on the exposed cross section of the stem. An adjustable spring governs the pressure at which the valve opens. For these tests the spring was adjusted to permit opening of the valve when a static pressure of approximately 1,600 lb./sq. in. was applied. The nozzle has two holes of 0.022 inch diameter, which direct the fuel against an impact lip.

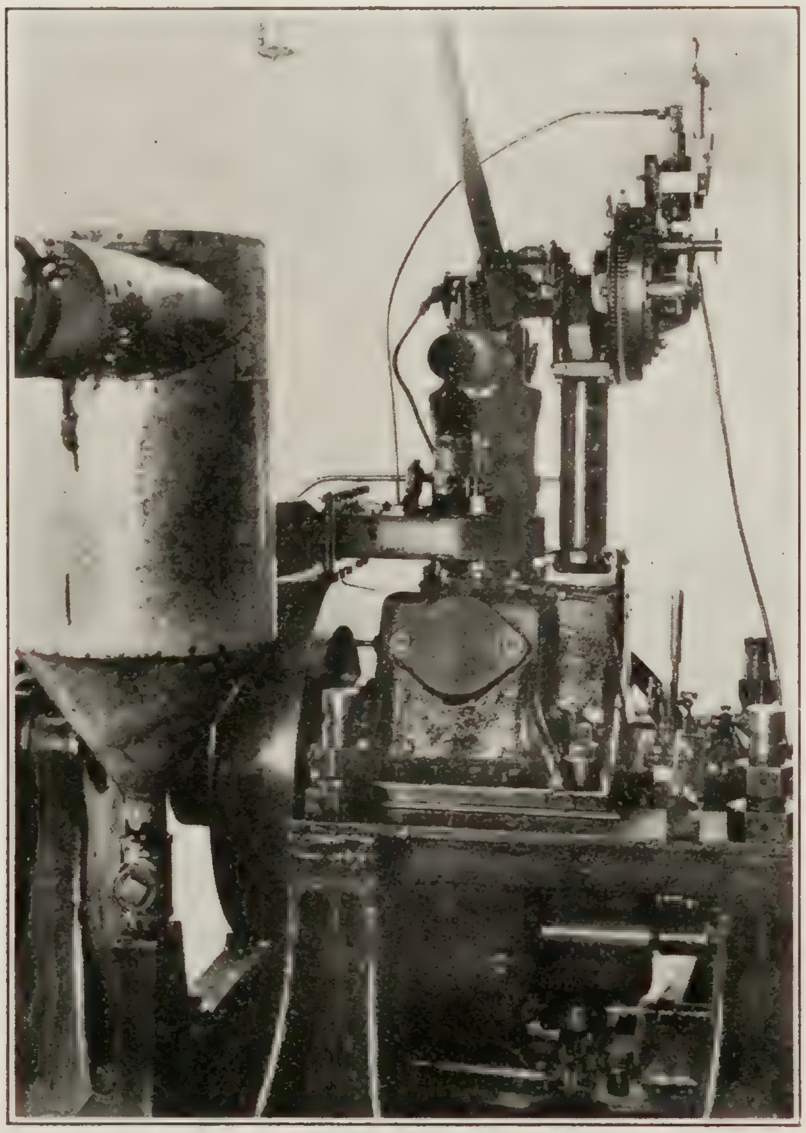


FIG. 6.—Liberty single cylinder two-stroke cycle engine

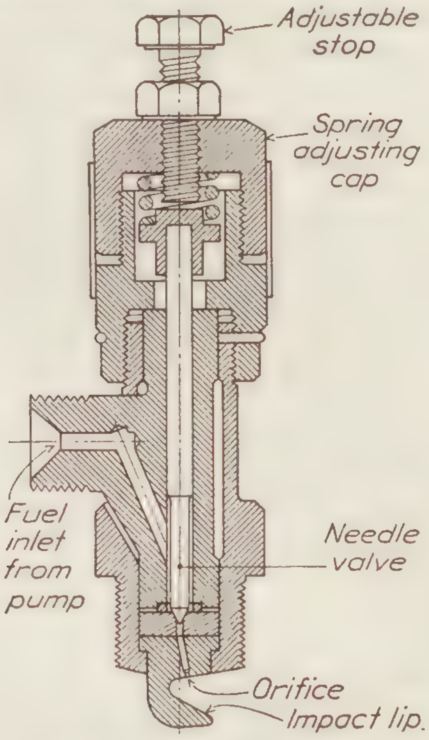


FIG. 7.—Fuel injection valve

The discharge characteristics of the complete fuel injection system have been reported in N. A. C. A. Technical Note No. 213.

METHOD OF TESTING

The method of obtaining the performance data was to operate the engine with a fixed air supply pressure, selecting by trial, a suitable pump stroke (fuel quantity) and pump timing to give maximum power with minimum fuel consumption at speeds of 1,000, 1,200, and 1,300 revolutions per minute. Tests were then made with the pump stroke reduced until a decrease of approximately 1 per cent in power was observed. In order to insure that the most suitable pump timing had been used, tests were also made with the timing both slightly advanced and retarded from the position originally selected. The air supply pressure was then increased and similar tests made. Air supply pressures from approximately 2 to 5.5 lb./sq. in. gauge, were used and the air and fuel consumption and power output determined for air-fuel ratios giving both maximum power and approximately 99 per cent maximum power.

The air consumption was determined as previously stated, with a standard 2-inch Durley orifice after special precautions had been taken to insure air flow, free from troublesome pressure fluctuations. A sensitive recording manometer (Reference 4) was used to determine the pressure fluctuations at the orifice and with its aid a combination of a throttling valve, rubber diaphragms, large capacity receivers and baffles was selected which reduced these fluctuations to a degree which was considered satisfactory. Since fluctuating pressures have been shown to tend to exaggerate the true amount of the air flow (Reference 5), the air quantities recorded are, if anything, slightly too large. Air-fuel ratios obtained during the tests, as computed from these air measurements indicate, however, that the air quantities were not unreasonably large. Pressure drop at the orifice was determined with an inclined manometer reading to 0.01 inch of water and the air supply pressures recorded were determined by means of a mercury manometer located at the large tank.

The fuel quantity was determined by calibrating the nozzle and pump. Fuel from the nozzle was weighed for a known number of cycles, while discharging at atmospheric pressure, thus making unnecessary any correction for leakage of the system. Since the pressure of the air into which the fuel was injected during the engine tests did not exceed 6.25 lb./sq. in. gauge, the calibration obtained by testing at atmospheric pressure was substantially correct.

The engine power was measured by means of an electric cradle-type dynamometer, and magnetically operated stop watch and revolution counter. Temperatures of air, oil, and cooling water were maintained approximately constant. Ignition was timed to occur at 30° advance, two spark plugs being used during all tests. Engine compression pressures were determined with a balanced piston indicator while the engine was being driven by the dynamometer.

RESULTS OF TESTS

The test results are presented in the form of curves, Figures 8 to 12, inclusive, all of which are observed performance at sea level. The rate of air flow, compression pressure, and observed brake horsepower resulting from changes in the air supply pressure are shown in Figure 8.

The curves representing air flow in lb./hr. are linear for all but the higher air pressures at 1,300 revolutions per minute. The air flow was apparently affected very little by change of engine speed over the range investigated and was largely dependent on the air supply pressure. Unsuitable valve gear design was probably responsible for the shape of the curve at 1,300 revolutions per minute. The curves of compression pressures are also linear for the range investigated.

It should be noted that it was possible to develop consistently 53 brake horsepower at 1,300 revolutions per minute with corresponding brake mean effective pressure of 116.5 lb./sq. in. This same engine when operated as a four-stroke cycle with a carbureter developed only 27.5 brake horsepower at this same speed. The curve for 1,300 revolutions per minute reaches a maximum at an air supply pressure of approximately 6 lb./sq. in., caused, presumably, by the decrease in air flow as indicated at this speed and pressure. Some brief tests were conducted with fuel injected directly into the cylinder, but the power output was much lower than when the fuel was injected into the entering air stream. As the primary object of making these tests was to determine the air requirements, no further attempt was made to develop direct-to-cylinder injection which might have possibilities equal to those of injection into the entering air.

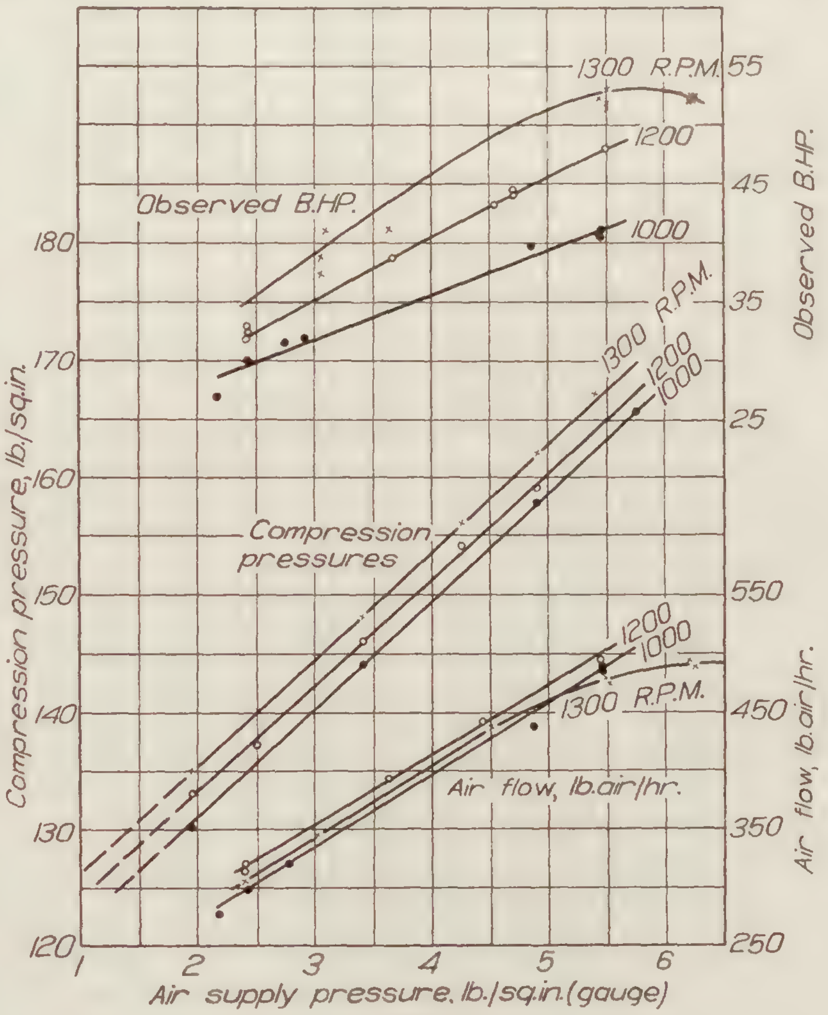


FIG. 8

It was found desirable, in order to reduce the tendency toward detonation, to use 8 cm^3 of ethyl fluid per gallon of domestic aviation gasoline. No pump trouble was experienced in using either gasoline alone or gasoline and ethyl fluid mixture. Even though the compression pressures varied over a wide range, the detonation remained fairly uniform in intensity during most of the runs. It was not thought severe enough to affect seriously the power output. Hot exhaust valves and reduction of the amount of residual exhaust gases (Reference 6), due to the scavenging air, both probably contributed to the tendency toward detonation. Experiments at the Bureau of Standards have shown that it is very difficult to scavenge a cylindrical chamber as completely by means of an air blast as by actually passing a piston throughout its length.[1] However, in the case of an actual engine cylinder, where the clearance space is of necessity not traversed by the piston, it is possible with air scavenging alone to equal or even exceed the scavenging accomplished in the conventional four-stroke cycle engine. In the case of a four-stroke cycle engine, 100 per cent scavenging of the displaced volume is accomplished by the piston, but the clearance volume remains practically unscavenged. In the case of the two-stroke cycle, herein described, although the displaced volume is incompletely scavenged by the air blast it is also possible by the same means to scavenge partially the clearance space. Thus it is conceivable that one might obtain better scavenging with the two-stroke cycle engine, using air scavenging alone, than that possible with a four-stroke cycle engine of conventional design.

It was observed that when the engine was operated with suitable pump timing, rich mixtures, and air supply pressures of 3.5 to 4 lb./sq. in. regular operation would continue without electric ignition if the cooling water temperatures were high enough. This would indicate either that some part within the combustion chamber was hot enough to cause self-ignition or that continuous burning was taking place. It was questioned whether exhaust valves were hot enough to cause self-ignition in the brief time interval available at these engine speeds (Reference 7). With the intention of determining whether increase of the amount of scavenging air would influence this self-ignition tendency, the engine was operated at several scavenging air pressures and the water temperatures increased until uniform operation was obtained without electric ignition. With an air supply pressure of 3.5 to 4 lb./sq. in. satisfactory operation without electric ignition was obtained when the water temperatures reached 150° F. The engine then continued to run without missing until the water temperature was reduced to 90° F. When the air supply pressure was increased to 5 lb./sq. in. self-ignition could not be obtained even with very high jacket water temperatures. This indicated that the increased amount of cold scavenging air, preceding injection of fuel, either prevented ignition by residual flame or so reduced the temperature of the hot parts as to eliminate self-ignition. As the tendency toward detonation is known to be increased by the presence of hot regions in the cylinder (Reference 8), this influence of the excess amount of cold scavenging air on combustion chamber temperatures probably also partially accounts for the fact that detonation was fairly uniform for all load conditions. This may be explained by the facts that as the fuel and air charges and compression pressure were increased, which would normally be expected to increase the detonation, the exhaust valve and combustion chamber temperatures tended to decrease due to the increased flow of cold scavenging air, the net result being practically uniform detonation for the range of air pressures investigated.

The assumption that excess amounts of scavenging air flow past the exhaust valves at air supply pressures above 3.2 lb./sq. in. is borne out by an examination of Figure 9, which shows the effect of changes in air supply pressure on the specific air consumption. It can be seen that above this pressure there is a marked increase in specific air consumption, indicating loss of air with exhaust gases. As previously explained, two distinct series of tests were made, one with mixture quality giving maximum power and the other slightly leaned until approximately 1 per cent decrease in power was observed, the corresponding curves being given in Figure 9. The specific air consumption depends on the mixture quality but the minimum occurs at 1,300 revolutions per minute with a full rich mixture and an air supply pressure of approximately 3.4 lb./sq. in. The minimum specific air consumption at 1,300 revolutions per minute was found to be approximately 8.35 lb./B.HP./hr. and may be compared with a value of 7.15 lb./B.HP./hr. consumed by a four-stroke cycle single-cylinder test engine of equal displacement when operated under similar conditions.

Figure 10 shows the relation between specific air and fuel consumption and the brake horsepower. It is interesting that both the minimum air and fuel consumptions occur at approximately the same power output and that any increase in power results in a substantial increase in both air and fuel consumption. The specific fuel consumption at 1,300 revolutions per minute reaches a minimum of 0.55 lb./B.HP./hr. when approximately 40 brake horsepower net is being developed or approximately 45 per cent more power than when operated on the four-stroke cycle. It is noteworthy, however, that the specific fuel consumption is increased by only approximately 12.5 per cent above its minimum value when the power output is increased to 50 brake horsepower net or approximately 82 per cent more power than that of the corresponding four-stroke cycle engine. Estimated power required to supply the necessary scavenging air has been subtracted from the observed brake horsepower of the engine in arriving at the net values given above.

---

[1] So far as the authors know these experiments have not been published.

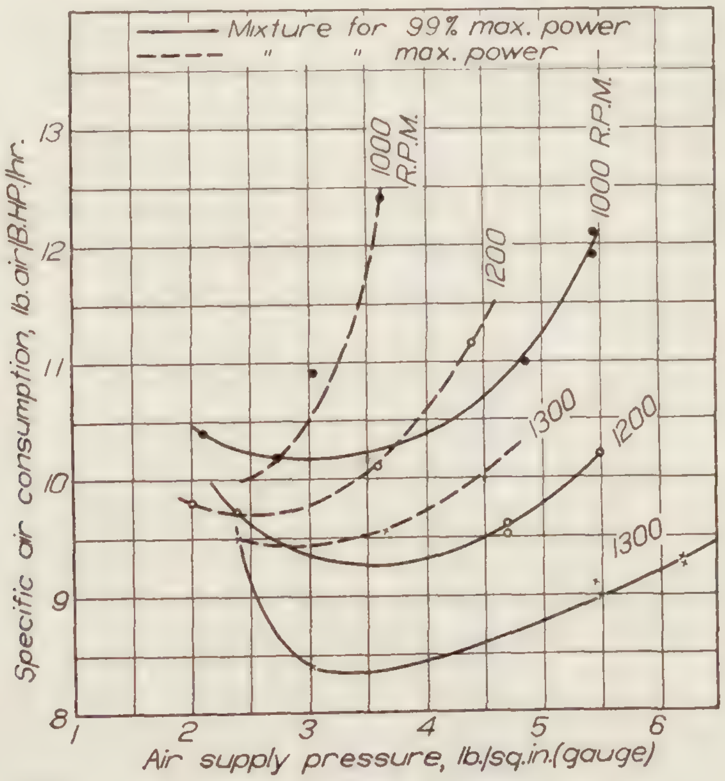


FIG. 9

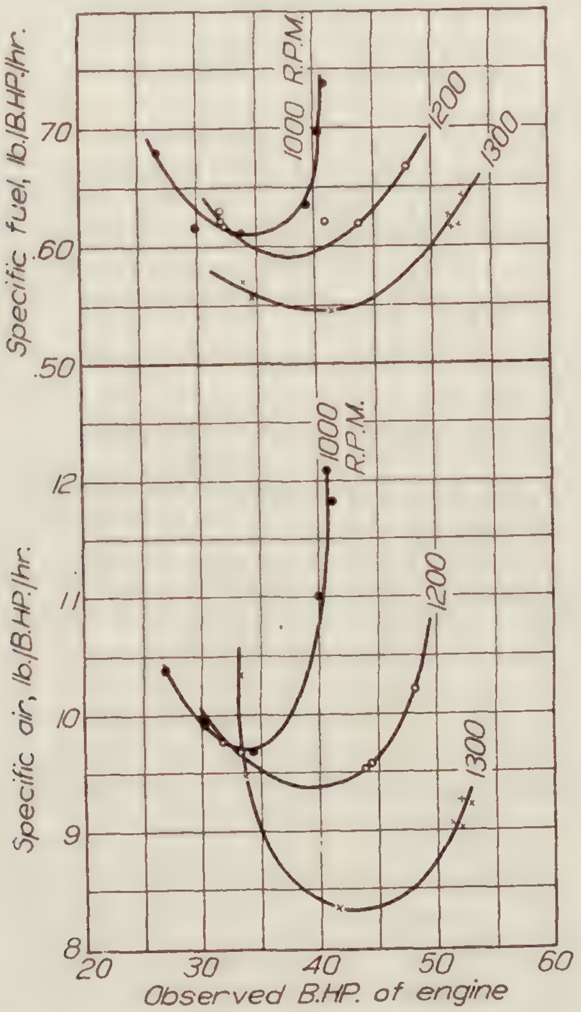


FIG. 10

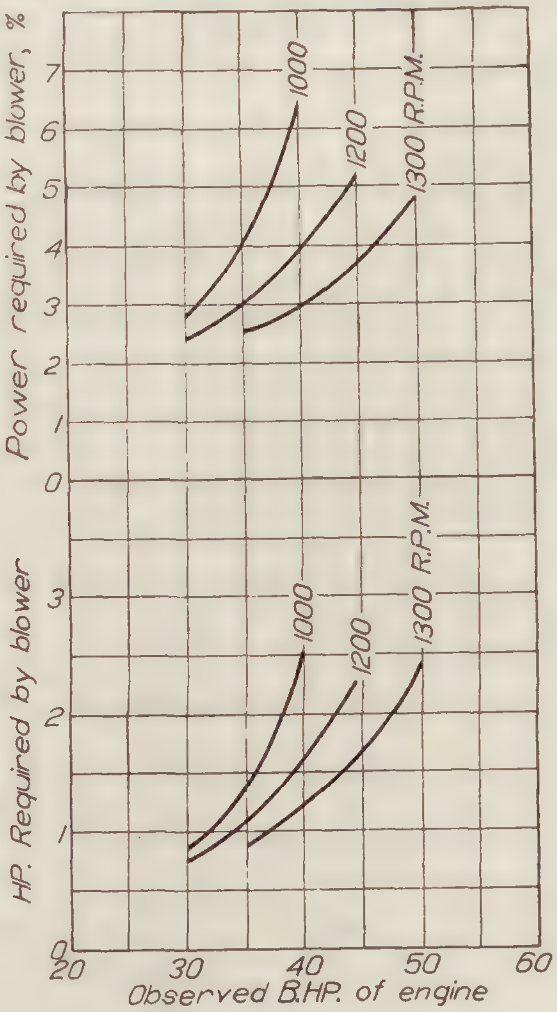


FIG. 11

The high specific fuel consumption of 0.61 lb./B.HP./hr. at 1,300 revolutions per minute, corresponding to a power output of 50 brake horsepower net, is partly due to the high friction horsepower (6.9) of the single cylinder Liberty base on which the tests were performed. Assuming that a multiple cylinder two-stroke cycle engine would have approximately the same friction horsepower as a four-stroke cycle aircraft engine of the same displacement, the fuel consumption with the above operating conditions would be reduced from 0.61 to 0.57 lb./B.HP./hr. Applying a correspnding reduction to all of the fuel consumption values would serve to make them more nearly approach those obtained with current aircraft engines.

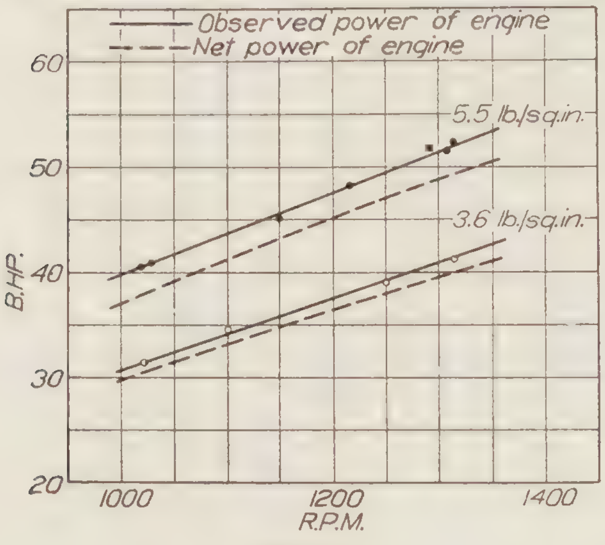


FIG. 12

Figure 11 shows the power required to suppy the air used by the engine when operating at speeds of 1,000, 1,200, and 1,300 revolutions per minute and delivering the power indicated. Power required by the blower is also shown in terms of percentage of the observed brake horsepower of the engine. These curves are based on the power requirements of the N. A. C. A. Roots type supercharger, a mechanical efficiency of 85 per cent being assumed. This efficiency is considered conservative as actual tests of the N. A. C. A. Roots supercharger have shown somewhat higher mechanical efficiencies than this assumed value. It will be readily appreciated that with suitable engine valve and port timing an oversize blower could be provided, thus serving to maintain the desired air pressure to a predetermined altitude.

Figure 12 shows both the observed and net power developed, plotted against revolutions per minute for air supply pressures of 3.6 and 5.5 lb./sq. in. gauge. These curves indicate that given suitable valve mechanism higher speeds than those investigated would be perfectly feasible.

CONCLUSIONS

The results of these tests, although incomplete, indicate that greatly increased power output, per unit of engine displacement, can be obtained with this two-stroke cycle engine, without the excessive fuel consumption usually associated with carbureted two-stroke cycle engines. A power output of 53 brake horsepower at 1,300 revolutions per minute or almost 85 per cent more than is developed in one cylinder of a standard Liberty 12 engine at the same speed, was consistently obtained with a 5 by 7 inch modified Liberty engine cylinder. Under these conditions specific air and fuel consumption of 9.0 and 0.61 lb./B.HP./hr. respectively, were obtained. Air was supplied, in the above case, for both scavenging and combustion at 5.5 pounds gauge pressure. The power required by a N. A. C. A. Roots type compressor of sufficient size to supply the necessary air, when the engine was operating at this power output, was estimated to be 3 horsepower. This figure might be reduced by using crankcase compression in conjunction with the compressor.

An engine of this type using airless injection, electric ignition, and blower scavenging and having the above performance characteristics, would seem to be worthy of consideration as a power plant for aeroplanes in which the primary engine requirement is the development of a large power output per unit of engine displacement, and fuel economy is relatively unimportant.

The engine did not give satisfactory operation at idling speeds, but no attempt was made to develop a design satisfactory in this respect as it was beyond the scope of this investigation.

The highest engine speed possible with the present design, using standard Liberty valves and valve gear, was 1,300 revolutions per minute, but it is felt that there would be no marked change in power, air or fuel consumption at somewhat higher speeds, as the trend of the curves show no decrease in power or increase in specific air or fuel consumption with increase in speed up to 1,300 revolutions per minute.

It is thought that suitable valves and valve mechanism would permit much higher engine speeds than were possible with the present engine, and that better results would be obtained by reversing the direction of gas flow through the cylinder so that the charge would enter through the valves and exhaust through the ports. This latter change would increase valve life, insure cool valves, which would materially reduce the tendency toward detonation, and should improve the operation at idling speeds. In the present design, a small idling charge can not reach the spark plugs without being so diluted as to prevent ignition or at least cause slow burning. Stratification of the combustible charge remote from the spark plugs, as would be the case in the present engine, would be detrimental, whereas, with the direction of gas flow reversed, a leading charge of scavenging air could be timed to precede the injection of fuel and thus leave a stratified charge of combustible mixture at the spark plugs.

REFERENCES AND BIBLIOGRAPHY

Reference 1. LIONEL S. MARKS: The Airplane Engine. p. 440.

2. MARSDEN WARE: Effect of the reversal of air flow upon the discharge coefficient of Durley orifices. N. A. C. A. Technical Note No. 40. 1921.

3. R. J. DURLEY: On the measurement of air flowing into the atmosphere through circular orifices in thin plates and under small differences of pressure. Transactions of American Society of Mechanical Engineers, 1906, vol. 27, p. 193.

4. F. H. NORTON: N. A. C. A. recording air speed meter. N. A. C. A. Technical Note No. 64. 1921.

5. JUDD and PHELEY: Effect of pulsations on flow of gases. Transactions of the American Society of Mechanical Engineers, 1922, vol. 44, p. 853.

6. J. F. ALCOCK: Inert diluents. Automobile Engineer, June, 1924. p. 165.

7. H. T. TIZARD: Self-ignition temperatures of fuels. The Automobile Engineer, May 1923, or Automotive Industries, June 24, 1923.

8. J. H. HOLLOWAY, H. A. HUEBOTTER, and G. A. YOUNG: Engine characteristics under high compression. Transactions of the Society of Automotive Engineers, 1923, vol. 18, Pt. I, p. 131.

REPORT No. 240

NOMENCLATURE FOR AERONAUTICS

By National Advisory Committee
For Aeronautics

INTRODUCTION

The nomenclature for aeronautics presented in this Report No. 240 is a revision of the last previous report on the subject (No. 157), which was issued in February, 1923.

This Nomenclature for Aeronautics was prepared by a special conference on aeronautical nomenclature authorized by the executive committee of the National Advisory Committee for Aeronautics at a meeting held on August 19, 1924, at which meeting Dr. Joseph S. Ames was appointed chairman of said conference. The conference was composed of representatives of the National Advisory Committee for Aeronautics, and, in response to the committee's invitation specially appointed representatives officially designated by the Army Air Service, the Bureau of Aeronautics of the Navy Department, the Bureau of Standards, the American Society of Mechanical Engineers, the Society of Automotive Engineers, and the Aeronautical Chamber of Commerce.

To facilitate the work of the conference the entire nomenclature was divided into four main sections, and a subcommittee was appointed to study and agree upon the terms for each section. These four subcommittees, with their officers, were as follows:

Subcommittee on Aerodynamic Terms.—Dr. Joseph S. Ames, chairman; Commander H. C. Richardson, United States Navy, vice chairman for airplanes and airplane parts; Dr. H. L. Dryden, vice chairman for aircraft instruments; and Prof. Edward P. Warner, vice chairman for maneuvers and general aerodynamics.

Subcommittee on Airship Terms.—Mr. Starr Truscott, chairman.

Subcommittee on Power Plant Terms.—Mr. G. W. Lewis, chairman.

Subcommittee on Airway Terms.—Lieut. St. Clair Streett, United States Army, chairman.

On completion of the reports of these four subcommittees, they were considered by the entire conference at a final meeting, and on recommendation of the conference the complete nomenclature was officially approved by the executive committee of the National Advisory Committee for Aeronautics on September 19, 1925.

This report supersedes all previous publications of the committee on this subject. It is published for the purpose of securing greater uniformity and accuracy in the use of terms relating to aeronautics, in official documents of the Government and, as far as possible, in technical and other commercial publications.

The organization of the conference on aeronautical nomenclature was as follows:

CONFERENCE ON AERONAUTICAL NOMENCLATURE

Dr. Joseph S. Ames, *Chairman*

National Advisory Committee for Aeronautics:
- Mr. G. W. Lewis.
- Prof. Edward P. Warner.
- Mr. Thomas Carroll.
- Mr. Marsden Ware.

Air Service of the Army:
- Maj. Harold A. Strauss, U. S. A.
- Capt. Gerald E. Brower, U. S. A.
- Mr. E. T. Jones.
- Capt. R. L. Walsh, U. S. A.
- Lieut. St. Clair Streett, U. S. A.

Bureau of Aeronautics, Navy Department:
- Commander H. C. Richardson, U. S. N.
- Dr. A. F. Zahm.
- Commander E. E. Wilson, U. S. N.
- Lieut. W. S. Diehl, U. S. N.
- Mr. Starr Truscott.

Bureau of Standards:
- Dr. H. C. Dickinson.
- Dr. H. L. Dryden.

American Society of Mechanical Engineers:
- Dr. W. F. Durand.

Society of Automotive Engineers:
- Mr. Grover C. Loening (also representing Aeronautical Chamber of Commerce).
- Mr. W. B. Stout.
- Mr. R. H. Upson.

Aeronautical Chamber of Commerce:
- Mr. S. S. Bradley.
- Mr. Ladislas d'Orcy.
- Mr. George Mead.
- Mr. Arthur L. Nutt.
- Mr. Grover C. Loening (also representing Society of Automotive Engineers).

REPORT No. 240

NOMENCLATURE FOR AERONAUTICS

By The National Advisory Committee for Aeronautics

PART I

ALPHABETICAL NOMENCLATURE

absolute inclinometer—See INCLINOMETER, ABSOLUTE.

accelerometer—An instrument for indicating, measuring, or recording accelerations.

aerodynamic volume—See VOLUME, AERODYNAMIC (AIRSHIP).

aerodynamics—The branch of dynamics which treats of the motion of air and other gaseous fluids and of the forces acting on solids in motion relative to such fluids.

aeronautics—The science and art pertaining to the flight of aircraft.

aerostat—A generic term for aircraft whose support is chiefly due to buoyancy derived from aerostatic forces. The immersed body consists of one or more bags, cells, or other containers, filled with a gas which is lighter than air.

Syn.—LIGHTER-THAN-AIR CRAFT. Includes airship and balloon, q. v.

aerostatics—The science that treats of the equilibrium of gaseous fluids and of solid bodies immersed in them.

As an aeronautic term, it relates to those properties of lighter-than-air craft which are due to the buoyancy of the air.

aerostation—The art of operating aerostats.

aileron—A hinged or pivoted movable auxiliary surface of an airplane, usually part of the trailing edge of a wing, the primary function of which is to impress a rolling moment on the airplane. (Fig. 1.)

aileron angle—See ANGLE, AILERON.

air controls—See CONTROLS.

aircraft—Any weight-carrying device or structure designed to be supported by the air, either by buoyancy or by dynamic action.

air duct—A tube, usually of fabric, supplying air for filling or for maintaining pressure in air-filled parts of an aerostat.

(*a*) The duct joining the vertical and lateral lobes of a kite balloon. Sometimes called "interconnecting sleeve" or "trousers" (British). (Fig. 2.)

(*b*) The duct leading from the air scoop or blower of a nonrigid or semirigid airship to the ballonet or ballonets. (Figs. 2 and 5.)

airfoil—Any surface designed to be projected through the air in order to produce a useful dynamic reaction.

airfoil section (or profile)—A cross section of an airfoil made by a plane parallel to a specified reference plane. A line perpendicular to this plane is called the axis of the airfoil.

air log—An instrument for measuring the linear travel of an aircraft relative to the air. One form consists of a windmill with a revolution counter.

airplane—A mechanically driven aircraft, heavier than air, fitted with fixed wings, and supported by the dynamic action of the air. (Figs. 1, 6, 9, 10, and 14.)

airplane, pusher—An airplane with the propeller or propellers in the rear of the main supporting surfaces. (Figs. 9 and 14.)

airplane, tandem—An airplane with two or more sets of wings of substantially the same area (not including the tail unit) placed one in front of the other and on about the same level.

airplane, tractor—An airplane with the propeller or propellers forward of the main supporting surfaces. (Figs. 1, 6, and 10.)

airport—A locality, either of water or land, which is adapted for the landing and taking off of aircraft and which provides facilities for shelter, supply, and repair of aircraft; or a place used regularly for receiving or discharging passengers or cargo by air.

air scoop—A projecting scoop which uses the wind or slip stream to maintain air pressure in the interior of the ballonet of an aerostat. (Figs. 2, 3, and 12.)

A similar device is sometimes used on airplanes to produce ventilation. (Fig. 4.)

airship—An aerostat provided with a propelling system and with means of controlling the direction of motion. When its power plant is not operating, it acts like a free balloon.

nonrigid—An airship whose form is maintained by the internal pressure in the gas bags and ballonets. (Fig. 3.)

rigid—An airship whose form is maintained by a rigid structure. (Fig. 4.)

semirigid—An airship whose form is maintained by means of a rigid or jointed keel in conjunction with internal pressure in the gas containers and ballonets. (Fig. 5.)

The term "airship" is sometimes incorrectly applied to heavier-than-air craft either in full or as "ship." This is a slang use of the word and should be avoided.

airship dope—See DOPE, AIRSHIP.

airship station—See STATION, AIRSHIP.

air speed—The speed of an aircraft relative to the air. Its symbol is V.

air-speed meter:

air-speed indicator—An instrument for indicating the speed of an aircraft relative to the air. It is actuated by the pressure developed in a suitable pressure nozzle or against a suitable obstruction and is graduated to give true air speed at a standard air density.

The speed indicated by the instrument is termed the "indicated air speed." (The indicated speed is a direct measure of the lift or drag exerted on the airplane at any altitude. Stalling at all altitudes occurs for the same value of the indicated speed.)

true air-speed meter—An instrument for measuring the true speed of an aircraft relative to the air. The Biram and Robinson anemometers are of this type.

air volume (airship)—See VOLUME, AIR (AIRSHIP).

air-volume displacement—See DISPLACEMENT, AIR VOLUME.

airway—An air route between air traffic centers which is over terrain best suited for emergency landings, with landing fields at intervals equipped with aids to air navigation and a communication system for the transmission of information pertinent to the operation of aircraft.

The term "airway" may apply to an air route for either landplanes or seaplanes or both.

alarm, gas-cell—A device, fitted adjacent to a gas cell, which indicates or warns when a predetermined limiting pressure has been reached in the gas cell. Also called "pressure alarm."

altigraph—An altimeter equipped with a recording mechanism. Present instruments are of the aneroid type. The chart, driven by clockwork, is usually graduated in feet or meters in accordance with some empirical or arbitrary pressure-temperature-altitude formula. In other words, it is a barograph whose scale is designed to read heights.

altimeter—An instrument for measuring or indicating the elevation of an aircraft above a given datum plane.

altimeter, aneroid—An altimeter, the indications of which depend on the deflection of a pressure-sensitive element. The graduations of the dial correspond to an empirical or arbitrary pressure-temperature-altitude formula.

altimeter, electrical-capacity—An altimeter, the indications of which depend on the variation of an electrical capacity with distance from the earth's surface.

altimeter, engine—An altimeter for indicating the altitude corresponding to the pressure produced in the intake manifold of a supercharged engine.

altimeter, optical—An altimeter, the indications of which depend on the manipulation of a suitable optical system.

altimeter, sound-ranging—An altimeter, the indications of which depend on the measurement of the time required for a sound wave to travel from the aircraft to the earth and back.

amphibian—An airplane designed to rise from and alight on either land or water.

anchor, sea—An open fabric bag carried on an aircraft and arranged to offer considerable resistance when towed mouth-first through the water. Tripping or collapsing devices may be incorporated in it. Also called "drogue."

anchorage, snatch-block—An anchorage set in the ground for a snatch block used with a yaw line from a mooring mast. The anchorages may be of concrete or timber and are usually arranged at equal intervals around the circumference of a circle whose center is the mast; may also be applied to any anchorage for a snatch block used in hauling down an airship or kite balloon.

anemometer—An instrument for indicating or measuring the speed of an air stream.

aneroid altimeter—See ALTIMETER, ANEROID.

angle, aileron—The angular displacement of an aileron from its neutral position. It is positive when the trailing edge of the aileron is below the neutral position.

angle, critical—An angle of attack at which the flow about an airfoil changes abruptly with corresponding abrupt changes in the lift and drag.

angle, downwash—The angle through which an air stream is deflected by any lifting surface of an airplane. It is measured in a plane parallel to the plane of symmetry and is denoted by the symbol ϵ.

angle, drift—The horizontal angle between the longitudinal axis of an aircraft and its path relative to the ground.

angle, effective helix—The angle of the helix described by a particular point on a propeller blade as the airplane moves forward through air otherwise undisturbed. It is equal to the angle whose tangent is the ratio of the velocity of flight to the product of the four quantities: $2\ \pi$, r (the distance from the axis to the point in question) and n (the number of revolutions per second), i. e.,

$$\Phi = \tan^{-1}\left(\frac{V}{2\pi r n}\right).$$

angle, elevator—The angular displacement of the elevator from its neutral position. It is positive when the trailing edge of the elevator is below the neutral position.

angle, landing—The acute angle between the line of thrust of an airplane and the horizontal when the airplane is resting on level ground in its natural position. Also called "ground angle." (Fig. 1.)

angle, longitudinal dihedral—The difference in angle of wing setting and of stabilizer setting. (This angle is positive when the angle of stabilizer setting, referred to the thrust line, is less than the angle of wing setting.)

angle, minimum gliding—The acute angle between the horizontal and the most nearly horizontal path along which an airplane can descend steadily in still air when the propeller is giving no thrust.

angle of attack—The acute angle between the chord of an airfoil and its direction of motion relative to the air. (This definition may be extended to other bodies than airfoils.) Its symbol is α.

angle of incidence of wing—See ANGLE OF WING SETTING.

angle of pitch—The acute angle between two planes defined as follows: One plane includes the lateral axis of the aircraft and the direction of the relative wind; the other plane includes the lateral axis and the longitudinal axis. (In normal flight the angle of pitch is, then, the angle between the longitudinal axis and the direction of the relative wind.) This angle is denoted by Θ and is positive when the nose of the aircraft has risen.

angle of roll, or angle of bank—The acute angle through which an aircraft must be rotated about its longitudinal axis in order to bring its lateral axis into a horizontal plane. This angle is denoted by Φ and is positive when the left wing is higher than the right.

angle of stabilizer setting—The acute angle between the line of thrust of an airplane and the chord of the stabilizer. (Fig. 1.)

angle of wing setting—The acute angle between the plane of wing chord and the line of thrust. It may differ for each wing. (Fig. 1.)

angle of yaw—The acute angle between the direction of the relative wind and the plane of symmetry of an aircraft. This angle is denoted by Ψ and is positive when the aircraft has turned to the right.

angle, propeller-blade—The acute angle between the chord of a propeller section and a plane perpendicular to the axis of rotation of the propeller. Usually called "blade angle."

angle, rudder—The acute angle between the rudder and the plane of symmetry of the aircraft. It is positive when the trailing edge has moved to the left with reference to the normal position of the pilot.

angle, wing-dihedral or dihedral—The acute angle between the transverse reference line in the wing surface and the lateral axis of the airplane projected on a plane perpendicular to the longitudinal axis. The dihedral angle is positive when the upper obtuse angle for the two wings is less than 180°. (Fig. 1.)

angle, zero-lift—The angle of attack of an airfoil when its lift is zero.

antiflutter wire—See WIRE (AIRSHIP), ANTIFLUTTER.

apparatus, water-recovery—Apparatus carried on an airship for condensing and recovering the water contained in the exhaust gases of internal combustion engines in order to avoid the necessity of valving gas as the fuel is consumed.

appendix—The tube, usually located at the bottom of a balloon, primarily used for inflation and deflation. In the case of a free balloon it may also serve as an automatic-discharge opening. (Fig. 11.)

Originally applied to free balloons only. Should be restricted to the various types of balloons and not applied to airships.

appendix manhole—See MANHOLE, APPENDIX.

apron—A hard surface area of considerable extent immediately in front of the entrance of a hangar or aircraft shelter which is used for the handling of aircraft or for repair in clear weather.

aspect ratio—The ratio of span to mean chord of an airfoil; i. e., the ratio of the square of the maximum span to the total area of an airfoil.

aspect ratio of propeller blade—Half the ratio of propeller diameter to maximum blade width.

attitude—The position of an aircraft as determined by the inclination of its axes to some frame of reference. If not otherwise specified, this frame of reference is fixed to the earth.

automatic valve—See VALVE, AUTOMATIC.

aviation—The art of operating heavier-than-air craft.

axes of an aircraft—Three fixed lines of reference, usually centroidal and mutually perpendicular. The longitudinal axis in the plane of symmetry, usually parallel to the axis of the propeller, is called the longitudinal axis; the axis perpendicular to this in the plane of symmetry is called the normal axis; and the third axis perpendicular to the other two is called the lateral axis. In mathematical discussions, the first of these axes, drawn from front to rear, is called the X axis; the second, drawn upward, the Z axis; and the third, running from right to left, the Y axis.

axial cable—See CABLE, AXIAL.

axial cone—See CONE, AXIAL.

bag, gas—See HULL (AIRSHIP), and CELL, GAS, which are to be preferred, according to the type and use.

balanced surface—A control surface which extends on both sides of the axis of the hinge or pivot in such a manner as to reduce the moment of the air forces about the hinge. (Figs. 1, 3, 4, and 5.)

ballast—Any substance, usually sand or water, carried in a balloon or airship and intended to be thrown out, if necessary, for the purpose of reducing the load carried and thus altering the aerostatic relations. (Figs. 4 and 5.)

ballonet—A compartment of variable volume constructed of fabric, or partitioned off, within the interior of a balloon or airship. It is usually partially inflated with air, under the control of valves, from a blower or from an air scoop. By the blowing in or letting out of air, it serves to compensate for changes of volume in the gas contained in the envelope and to maintain the gas pressure, thus preventing deformation or structural failure. By means of two or more ballonets, often used in nonrigid airships, the trim can also be controlled. The ballonet should not be confused with gas cell. (Figs. 2, 3, and 5.)

ballonet diaphragm—See DIAPHRAGM, BALLONET.

ballonet-fullness indicator—See INDICATOR, BALLONET-FULLNESS.

balloon—An aerostat without a propelling system.

barrage—A small captive balloon, used to support wires or nets which are intended as a protection against attacks by aircraft.

captive—A balloon restrained from free flight by means of a cable attaching it to the earth.

constant pressure*—A supply balloon arranged to maintain a constant pressure of gas in a moored or docked aerostat.

free—A balloon, usually spherical, whose ascent and descent may be controlled by use of ballast or with a loss of the contained gas, and whose direction of flight is determined by the wind. (Fig. 11.)

kite—An elongated form of captive balloon, fitted with lobes to keep it headed into the wind and usually deriving increased lift due to its axis being inclined to the wind. (Fig. 2.)

nurse*—Sometimes used to refer to a constant-pressure balloon.

observation—A captive balloon used to provide an elevated observation post.

pilot*—A small balloon sent up to show the direction and speed of the wind.

propaganda—A small free balloon sent up without passengers but with a device by which papers or documents may be dropped at intervals.

sounding*—A small balloon sent up without passengers but with recording meteorological instruments.

supply*—A container made of heavy fabric employed as a portable means of storing gas at low pressure. It is usually too heavy to rise, even if free.

triangulation*—A small captive balloon used as a mark on which to sight in a triangulation survey.

balloon bed—A mooring place on the ground for a captive balloon.

balloon fabric—See FABRIC, BALLOON.

band:

drip—See FLAP, DRIP.

mooring—A band of tape or webbing, over the top of a kite balloon, to which the mooring ropes are attached. It forms part of a mooring harness. (Fig. 2.)

suspension—A horizontal fabric band, securely fastened to the envelope of a balloon or airship, and to which are attached the main suspensions of the basket or car, or the captive cable of a kite balloon. (Fig. 2.)

trajectory—A band of webbing carried in a special curve over the surface of the envelope of an airship to distribute the stresses due to the suspension of the car. (Fig. 13.)

---

* Those forms of balloons marked with an asterisk (*) are not, strictly speaking, aircraft.

bank—To incline an airplane laterally, i. e., to rotate it about its longitudinal axis. Right-bank is to incline the airplane with the right wing down.

Also used as a noun to describe the position of an airplane when its lateral axis is inclined to the horizontal.

bank, angle of—See ANGLE OF ROLL.

barograph—An instrument for recording the barometric or static pressure of the atmosphere.

barrage balloon—See BALLOON, BARRAGE.

barrel-type engine—See ENGINE, BARREL-TYPE.

bar, suspension—A bar to which the supporting ropes of the basket of a balloon are secured. It is also fitted with ropes and toggles for attaching to the basket suspensions from the balloon. Also called "trapeze bar." (Figs. 2 and 11.)

basic load—See LOAD, BASIC.

basket—The structure suspended beneath a balloon, for carrying passengers, ballast, etc. (Figs. 2 and 11.)

It is usually used on a free or kite balloon.

batonet—A special form of toggle, usually quite slender and truly cylindrical, except for the groove, and used to attach the rigging of a balloon or airship to a fabric loop or suspension band on the envelope.

bay (body parts)—The portion of a face of a truss, or of a fuselage, between adjacent bulkheads or adjacent struts or frame positions.

biplane—An airplane with two main supporting surfaces placed one above the other. (Fig. 1.)

blade back—The side of a propeller blade which corresponds to the upper surface of an airfoil.

blade face—The surface of a propeller blade which corresponds to the lower surface of an airfoil. Sometimes called "thrust face," or "driving face."

blade-width ratio—The ratio of the developed width of a propeller blade at any point to the circumference of a circle whose radius is the distance of that point from the propeller axis.

blimp—A small nonrigid airship. "Airship" is to be preferred.

body—The fuselage or hull, or nacelle (including cowling and covering) and nacelle mounting. (Figs. 1, 6, 9, 10, and 14.)

bonnet—See HOOD, VALVE.

bow cap—See CAP, BOW.

bow-heavy—The condition of an airship which, when at rest in still air, trims with its axis inclined down by the bow. The term "bow-heavy" is preferred to "nose-heavy" in describing airships.

bow-steadying line—See LINE, YAW.

bow stiffener—See STIFFENER, BOW.

box girder—See GIRDER, BOX.

brake mean effective pressure—The net unit pressure which, if applied during the power strokes to the pistons of an engine having no mechanical losses, would produce the given brake horsepower at the stated speed.

breathing—The passage of air into or out of an aerostat, due to the changing of its volume.

breathing stresses—See STRESSES, BREATHING.

bridle—A sling of cordage or wire which has its ends fixed at two different points, to the bight of which a single line may be attached, either movable or fixed, thus distributing the pull of the single line to two points or more in the case of a multiple bridle. This term is also used to refer to a towing or mooring line having two legs and intended to reduce yawing when towing or mooring.

building cradle—See CRADLE, BUILDING.

bullseye—A circular thimble.

buoyancy—The upward air force on an aerostat which is derived from aerostatic conditions. It is equal to the weight of the air displaced.

buoyancy, center of (aerostat)—The center of gravity of the volume of the contained gas.

cabane—A framework for supporting the wings at the fuselage; also applied to the system of trussing used to support overhang in a wing. (Figs. 6, 9, and 10.)

cable, axial—The axial member (usually steel wire cable) sometimes fitted in a rigid airship. It is attached to the central fitting of the radial or diametral wires of each main transverse and to the hull structure at bow and stern. Its purpose is to provide support for the radial or diametral wires in an axial direction and thus assist them to sustain the load which might be caused by unequal pressure in adjacent cells or by the airship being pitched to a large angle. (Fig. 4.)

camber—The rise in the curve of an airfoil section from its chord, usually expressed as the ratio of the departure of the curve from the chord to the length of the chord. "Upper camber" refers to the upper surface of an airfoil and "lower camber" to the lower surface; "mean camber" is the mean of these two.

capacity—The volume of the gas-containing portion of an aerostat.

capacity, nominal gas—The volume of the envelope of gas cells of an aerostat under certain conditions of pressure and inflation which have been defined. It is rarely the same as the true full volume. This is usually very difficult to determine accurately, especially in the case of rigid airships. Sometimes called "volume."

cap, bow—(1) A cap of metal or fabric used to reinforce the extreme forward ends of the bow stiffeners of a nonrigid or semirigid airship. (Figs. 3 and 5.)

(2) The conical or cap-shaped structure at the extreme bow of a rigid airship to which the longitudinal girders are attached and which supports the bow mooring spindle. (Fig. 4.)

cap, nose—See CAP, BOW, which is to be preferred.

captive balloon—See BALLOON, CAPTIVE.

car—That portion of an airship which is intended to carry power unit or units, personnel, cargo, or equipment. It may be suspended from the buoyant portion, or it may be built close up against it. It is not to be applied to parts of the keel of a rigid or semirigid airship which have been fitted for the purposes mentioned. (Figs. 3, 4, 5, 12, and 13.)

car, control—The car of an airship in which controls are centralized and from which it is operated. (Figs. 3, 4, 5, 12, and 13.)

carrier, fin—A frame to which the inboard edge of the fin of a nonrigid or semirigid airship is attached, so as to prevent the edge of the fin from sinking into the envelope. (Fig. 5.)

car, side—See CAR, WING.

car, wing—A car suspended off the center line of an airship. It is also called "side car." (Fig. 4.)

catenary—A line or length of cordage which is secured to or in a piece of fabric in the form of a catenary curve or a series of such curves. (Fig. 5.)

ceiling:

absolute—The maximum height above sea level at which a given airplane would be able to maintain horizontal flight, assuming standard air conditions.

service—The height above sea level, assuming standard air conditions, at which a given airplane ceases to be able to rise at a rate higher than a small specified one (100 feet per minute in the United States and England). This specified rate may be different in different countries.

ceiling, static—The altitude in standard atmosphere, at which an aerostat is in static equilibrium after removal of all dischargeable weights.

cell, gas—One of the gas-containing units fitted in a rigid airship. Sometimes called "gas bag." (Fig. 4.)

center of buoyancy—See BUOYANCY, CENTER OF (AEROSTAT).

center of pressure coefficient—The ratio of the distance of the center of pressure from the leading edge to the chord length.

center of pressure of an airfoil section—The point in the chord of an airfoil section, prolonged if necessary, which is at the intersection of the chord and the line of action of the resultant air force. Its abbreviation is *C. P.*

chafing patch—See PATCH, CHAFING.

channel patch—See PATCH, CHANNEL.

chord (**of an airfoil section**)—The line of a straight edge brought into contact with the lower surface of the section at two points; in the case of an airfoil having double convex camber, the straight line joining the leading and trailing edges. (These edges may be defined, for this purpose, as the two points in the section which are farthest apart.) (Fig. 1.) The line joining the leading and trailing edges should be used also in those cases in which the lower surface is convex except for a short flat portion.

The method used for determining the chord should always be explicitly stated for those sections with regard to which ambiguity seems likely to arise.

chord length—The length of the projection of the airfoil section on its chord. Its symbol is c.

chord, mean, of a combination of wings—The ratio—

$$\frac{c_1S_1+c_2S_2+c_3S_3+\ \ldots\ldots}{S_1+S_2+S_3+\ \ldots\ldots}$$

where c_1, c_2, c_3, etc., are the mean chords of various wings, and S_1, S_2, S_3, etc., are their areas.

chord, mean, of a wing—The quotient obtained by dividing the wing area by the extreme dimension of the wing projection at right angles to the chord.

chord wire—See WIRE (AIRSHIP), CHORD.

climb, rate of—See RATE OF CLIMB.

climbing shaft—See SHAFT, CLIMBING.

cloth—Fabric delivered by the bleachery or finisher before it has been proofed, doped, or specially treated for aeronautic use.

cloth, ground—Canvas placed beneath an aerostat for its protection during inflation and deflation.

cockpit—The open spaces in which the pilot and passengers are accommodated. (Fig. 1.) When the cockpit is completely housed in it is called a cabin. (Figs. 1, 6, 9, 10, and 14.)

compartment, control—A compartment in the control car of an airship from which all controls are operated. It may be compared to the pilot house of a ship.

compass, induction—A compass, the indications of which depend on the current generated in a coil revolving in the earth's magnetic field.

concentration ring—See RING, CONCENTRATION.

condenser, water-recovery—That part of the water-recovery apparatus which is devoted to the condensing of water in the exhaust gases. It may consist of a number of metal tubes or of a fabric box with appropriate inlets, outlets, and baffles.

cone, axial—The cone-shaped fabric, fitting in the end of a gas cell of a rigid airship, which provides a gas-tight connection of the cell to the axial cable and yet permits the cell some degree of freedom in its movements. A special form of conical sleeve. (Fig. 4.)

cone, danger—A pennant on the wire cable of a captive balloon to warn aircraft of its presence. Usually a hollow cone of light cloth.

cone, mooring—The grooved conical member at the extreme bow of an airship which engages with a hollow cone at the top of the mooring mast and provides the coupling between the airship and the mooring mast. (Fig. 4)

conical sleeve—See SLEEVE, CONICAL.

container, gas—See CELL, GAS, which is to be preferred.

control car—See CAR, CONTROL.

control compartment—See COMPARTMENT, CONTROL.

controllability—The quality in an airplane which makes it possible for the pilot to change its attitude easily and with the exertion of but little force.

control lines—See LINES, CONTROL.

controls—A general term applied to the means provided to enable the pilot to control the speed, direction of flight, attitude, and power of an aircraft.

air controls—The means employed to operate the control surfaces of the aircraft.

engine controls—The means employed to control the power output of the engines. (Control of speed may be effected by the air controls or the engine controls independently, or by either in conjunction with the other.)

control stick—The vertical lever by means of which the longitudinal and lateral controls of an airplane are operated. Pitching is controlled by a fore-and-aft movement of the stick, rolling by a side-to-side movement. (Fig. 1.)

control surface—See SURFACE, CONTROL.

cord grommet—See GROMMET.

cord netting—See NET, GAS CELL (RIGID AIRSHIP).

cord, rip.—The rope running from the rip panel to the car or basket, the pulling of which tears off or rips the rip panel and causes immediate deflation. (Figs. 2 and 3.)

cover, outer—The outside covering of the hull of a rigid airship, usually of some kind of fabric. Sometimes called the "envelope." (Figs. 4 and 5.)

cover, valve—See HOOD, VALVE.

cowling—A removable covering which extends over or around the engine, and sometimes over a portion of the fuselage or nacelle as well. (Figs. 1, 6, 10, and 14.)

cradle:

- **building**—A support provided for the frame of a rigid airship or the keel of a semirigid airship during construction.
- **docking**—A support for the car of an airship while it is being inflated in the shed. Mostly used with rigid airships.

crew, ground—See CREW, LANDING.

crew, landing—A detail of men necessary for the landing and handling of an airship on the ground. A "ground crew."

critical angle—See ANGLE, CRITICAL.

critical speed—See SPEED, CRITICAL.

cross-country flight—See FLIGHT, CROSS-COUNTRY.

cross-wind force—See FORCE, CROSS-WIND.

crow's-foot—A system of diverging short ropes for distributing the pull of a single rope.

An arrangement in which the strands of a cord are opened out so that they can be effectively cemented to a fabric surface.

cruciform girder—See GIRDER, CRUCIFORM.

damping factor—The factor $e-{}^{\lambda t}$ in the equation of damped harmonic motion.

$$s = Ae-{}^{\lambda t} \sin pt.$$

danger cone—See CONE, DANGER.

dead load—See WEIGHT, EMPTY, which is to be preferred.

decalage—The acute angle between the wing chords of a biplane or multiplane. (Fig. 1.)

deflation—The act of removing gas and air from an aerostat.

deflation sleeve—See SLEEVE, DEFLATION.

diametral wire—See WIRE (AIRSHIP), DIAMETRAL.

diaphragm, ballonet—The fabric partition between the gas and air compartments of the envelope of a nonrigid or semirigid airship or kite balloon.

dihedral angle.—See ANGLE, WING-DIHEDRAL.

dirigible—That can be directed; steerable; as a dirigible balloon. Its use as a noun to indicate an airship is improper.

dischargeable weight—See WEIGHT, DISCHARGEABLE.

displacement—The mass of air displaced by the gas used for inflation. It may be expressed as a weight or volume. In the latter case it is usually called "volume."

displacement, aerodynamic volume or air volume—The weight of a mass of air equal to the aerodynamic volume of the airship in N. A. C. A. standard atmosphere at sea level.

disposable weight—See WEIGHT, DISPOSABLE (AIRSHIP).

dive—A steep descent, with or without power, in which the air speed is greater than the maximum speed in horizontal flight.

divergence—A motion in which, after a disturbance from equilibrium, the body departs continuously, without oscillations, from its original state of motion.

dock—A term sometimes applied to an airship shed.

docking cradle—See CRADLE, DOCKING.

docking rail—See RAIL, DOCKING.

docking trolley—See TROLLEY, DOCKING.

dope (airplane)—The liquid material applied to the cloth surfaces of airplanes to increase strength, to produce tautness by shrinking, and to act as a filler for maintaining air-tightness.

dope (airship)—The liquid material applied to rubberized airship fabric to increase gas-tightness. In contrast with airplane dope, it does not cause shrinking.

dope (pigmented)—An aircraft dope to which a pigment has been added to make an opaque finish, or to protect it from the effects of sunlight.

downwash angle—See ANGLE, DOWNWASH.

drag—The component parallel to the relative wind of the total air force on an aircraft or airfoil. Its symbol is D.

The "absolute drag coefficient" is C_D as defined by the equation $C_D=\frac{D}{qS}$, in which D is the drag, q is the impact pressure $(=\frac{1}{2}\rho V^2)$ and S is the effective area of the surface upon which the air force acts.

In the case of an airplane, that part of the drag due to the wings is called "wing drag"; that due to the rest of the airplane is called "structural drag" or "parasite resistance."

induced—That portion of the wing drag induced by, or resulting from, the generation of the lift.

profile—That portion of the wing drag which is due to friction and turbulence in the fluid and which would be absent in a nonviscous fluid.

drag, mooring—A movable and/or variable weight, suspended from the after part of an airship's structure while moored at a mast, to aid in restraining the vertical and lateral motions of the stern of the airship.

drag-rope—See ROPE, DRAG.

drag strut—See STRUT, DRAG.

drift—The lateral velocity of an aircraft due to air currents.

drift angle—See ANGLE, DRIFT.

drift bar—A part of a drift meter or other instrument for indicating the apparent direction of motion of the ground relative to the fore-and-aft axis of the aircraft. It usually consists of a wire or arm which can be set along this direction of motion. Cf. drift.

drift meter—An instrument for measuring the angle between the fore-and-aft axis of an aircraft and its path over the ground. One form consists of a drift bar provided with a suitable angular scale. (Cf. drift.) The instrument is graduated to read correctly when it is level.

drip band—See FLAP, DRIP.

drip flap—See FLAP, DRIP.

drip strip—See FLAP, DRIP.

D—**ring**—A ring having (as the name implies) the shape of a capital D, to which rope suspensions are attached.

drogue—See ANCHOR, SEA.

dry weight of an engine—See ENGINE, DRY WEIGHT OF.

duralumin—An alloy of aluminum which is much used in aeronautics, especially for the structure of airships and airplanes. Its chemical composition and physical properties are about as follows:

Copper, 3.5 to 4.5 per cent.
Manganese, 0.4 to 1 per cent.
Magnesium, 0.2 to 0.75 per cent.
Aluminum, 92 per cent, minimum.
Tensile strength, ultimate, 55,000 pounds per square inch.
Tensile strength at elastic limit, 30,000 pounds per square inch.
Elongation of 2 inches at ultimate strength (test specimen ½ inch wide), 18 per cent.
Specific gravity not more than 2.85.

dynamic factor—The ratio between the load carried by any part of an aircraft when accelerating and the corresponding basic load.

dynamic lift—See LIFT, DYNAMIC.

dynamic load—See LOAD, DYNAMIC.

dynamic (or **impact**) **pressure**—The product $\frac{1}{2}\rho V^2$, where ρ is the density of the air and V is the relative speed of the air. It is the quantity measured by most air-speed instruments. Its symbol is q.

dynamic trim—See TRIM, DYNAMIC.

economic speed—See SPEED, ECONOMIC.

effective helix angle—See ANGLE, EFFECTIVE HELIX.

effective thrust—See THRUST, EFFECTIVE.

elevator—A movable auxiliary airfoil, the function of which is to impress a pitching moment on the aircraft. The elevator is usually hinged to the stabilizer. (Figs. 1, 3, 4, 5, 6, 9, 10, 13, and 14.)

elevator angle—See ANGLE, ELEVATOR.

endurance—The maximum length of time an aircraft can remain in the air at a given speed and altitude.

engine altimeter—See ALTIMETER, ENGINE.

engine, barrel-type—An engine having its cylinders arranged equidistant from and parallel to the main shaft.

engine controls—See CONTROLS.

engine, dry weight of an—The weight of the engine, including carburetor and ignition systems complete, propeller hub assembly, reduction gears, if any, but excluding exhaust manifolds, oil, and water. If the starter is built into the engine as an integral part of the structure its weight shall be included.

engine, inverted—An engine having its cylinders below the crankshaft.

engine, left-hand—An engine whose propeller shaft, to an observer facing the propeller from the antipropeller end of the shaft, rotates in a counterclockwise direction.

engine, radial—An engine having stationary cylinders arranged radially around a common crankshaft.

engine, right-hand—An engine whose propeller shaft, to an observer facing the propeller from the antipropeller end of the shaft, rotates in a clockwise direction.

engine, rotary—An engine having revolving cylinders arranged radially around a common fixed crankshaft.

engine, supercharged—An engine with mechanical means for increasing the cylinder charge beyond that normally taken in at the existing atmospheric pressure and temperature.

engine, vertical—An engine having its cylinders arranged vertically above the crankshaft.

engine, V-type—An engine having its cylinders arranged in two rows, forming, in the end view, the letter "V."

engine, W-type—An engine having its cylinders arranged in three rows, forming, in the end view, the letter "W." Sometimes called the "broad-arrow type."

entering edge—See LEADING EDGE.

envelope—The outer covering of an aerostat, usually of fabric. It may or may not be also the gas container. It may be divided by diaphragms into separate gas compartments or cells, and it may also contain internal air cells or ballonets. (Figs. 2, 3, 4, 5, 11, 12.)

equipment, ground—See GEAR, GROUND.

fabric, balloon—The finished material, usually rubberized, of which balloon or airship envelopes are made.

biased—Plied fabric in which the threads of the plies are at an angle to each other.

parallel—Plied fabric in which the threads of the plies are parallel to each other.

fabric, gas-cell—The fabric used in gas cells of rigid airships, usually goldbeater's skin fabric, q. v.

fabric, goldbeater's skin—A gas containing fabric consisting of a layer of light, fine, strong cloth, usually cotton, to which one or more layers of goldbeater's skins have been cemented. The skins are on the inside and are usually further protected by a coat of fine varnish. Usually used in the gas cells of rigid airships.

factor, dynamic—See DYNAMIC FACTOR.

factor of safety—The ratio of the ultimate strength of a member to the maximum probable load in that member in actual use.

fairing—An auxiliary member or structure whose primary function is to reduce head resistance or drag of the part to which it is fitted (without, in general, contributing strength).

fairing wire—See WIRE, FAIRING.

field-handling frame—See FRAME, FIELD-HANDLING.

filling sleeve—See SLEEVE, FILLING.

fin—A fixed surface, attached to a part of the aircraft, parallel to the longitudinal axis, in order to secure stability; for example, tail fin, skid fin, etc. Fins are sometimes adjustable. (Figs. 1, 3, 4, 5, 6, 9, 10, 13, and 14.)

fin carrier—See CARRIER, FIN.

fin girder—See GIRDER, FIN.

finger patch—See PATCH, FINGER.

fire wall—A fire-resistance transverse bulkhead, so set as to isolate the engine compartment from the other parts of the structure and thus to reduce the risk from fire in the engine compartment. (Fig. 1.)

fitting—A generic term for any small part used in the structure of an airplane or airship. If without qualification, a metal part is usually understood. It may refer to other parts, such as "fabric fittings."

fixed fuel tank—See TANK, FIXED FUEL.

fixed power-plant weight for a given airplane—See WEIGHT, FIXED, POWER-PLANT, FOR A GIVEN AIRPLANE.

fixed surface—See FIN.

fixed weight—See WEIGHT, FIXED (AIRSHIP).

flap, drip—A strip of fabric attached by one edge to the envelope of an aerostat so that rain runs off its free edge instead of dripping into the basket or car. It also assists in keeping the suspension ropes dry and nonconducting. Also called "drip band" and "drip strip."

flap, pressure—A flap valve fitted in the outer cover or envelope of a rigid airship and arranged to permit the rapid flow of air in and out—particularly inward. The purpose is to facilitate the rapid equalization of the pressure of the air within the envelope with that of the surrounding air.

flight, cross-country—A flight which necessitates leaving the vicinity of a regular landing field.

flight indicator—See INDICATOR, FLIGHT.

flight path—The path of the center of gravity of an aircraft with reference to the earth.

flight recorder—See RECORDER, FLIGHT.

float—A completely inclosed water-tight structure attached to an aircraft in order to give it buoyancy and stability when in contact with the surface of the water. In float seaplanes the crew is carried in a fuselage or nacelle separate from the float. (Fig. 10.) The term "pontoon" is now obsolete.

flotation gear—See GEAR, FLOTATION.

flying boat—A form of seaplane supported, when resting on the surface of the water, by a hull or hulls providing flotation in addition to serving as fuselages. (Fig. 9.) For the central hull type, lateral stability is usually provided by wing-tip floats. The term "boat seaplane" is now obsolete.

force, cross-wind—The component, perpendicular to the lift and to the drag, of the total air force on the aircraft or any part thereof. Its symbol is C and its absolute coefficient C_C is defined by

$$C_C = \frac{C}{qS}$$

where q is the impact pressure $(=\frac{1}{2}\rho V^2)$ and S is the effective area of the surface upon which the air force acts.

frame, field-handling—A portable frame which may be attached to an airship when it is on the ground and which is intended to afford a grasp to more men than could get on the handling rails of the cars. These frames are rarely carried when in flight. (Fig. 4.)

framing, stern—All framework, aft of the cruciform girder, necessary to complete the shape and contour of a rigid airship.

free balloon—See BALLOON, FREE.

free-balloon net—See NET, FREE-BALLOON.

fuel (or oil) consumption, specific—The weight of fuel (or oil) consumed per brake horsepower-hour.

fuel tank, fixed—See TANK, FIXED FUEL.

full load—See LOAD, FULL.

fuselage—The structure, of approximately streamline form, to which are attached the wings and tail unit of an airplane. In general it contains the power plant, passengers, cargo, etc. (Figs. 1, 6, and 10.)

fuselage, monocoque.—A type of fuselage construction wherein the structure consists of a thin shell of wood, metal, or other material, supported by ribs, frames, belt frames, or bulkheads, but usually without longitudinal members other than the shell itself. The whole is so disposed as to carry the stresses to which the structure is subjected. (Fig. 6.)

gap—The distance between the planes of the chords of any two adjacent wings, measured along a line perpendicular to the chord of the upper wing at any designated point of its leading edge. (Fig. 1.) Its symbol is G.

gas bag—See HULL (AIRSHIP) and CELL, GAS.

gas capacity, nominal—See CAPACITY, NOMINAL GAS.

gas cell—See CELL, GAS.

gas-cell alarm—See ALARM, GAS-CELL.

gas-cell fabric—See FABRIC, GAS-CELL.

gas-cell, net—See NET, GAS-CELL (RIGID AIRSHIP).

gas container—See CELL, GAS.

gas shaft—See SHAFT, GAS.

gas-shaft hood—See HOOD, GAS-SHAFT.

gassing—The operation of replenishing a balloon with fresh gas to increase the purity or to make up for loss of gas.

gassing factor—The quantity of aerostatic gas required to maintain an aerostat for one year. It is ordinarily expressed as a percentage of the gas volume.

gas volume—See VOLUME, GAS (AIRSHIP).

gear, flotation—An emergency gear attached to a landplane to permit alighting on the water and to provide buoyancy when resting on the surface of the water.

gear, ground—The gear, or equipment, necessary for the landing and handling of an airship on the ground.

girder, box—Any girder of rectangular section. Frequently used to refer to the rectangular, longitudinal members in the keel of a rigid airship from which fuel tanks and gas bags are suspended.

girder, cruciform—The structure, consisting of vertical and horizontal transverse girders, which is fitted at the stern of a rigid airship for the purpose of supporting the inboard ends of the stern posts of the fins or the rudder posts. It may be integral with the stern posts which form the after ends of the fins.

girder, fin—A girder of a rigid airship which goes to make up the fin.

girder, propeller reinforcing—A light additional member fitted in the structure of a rigid airship to reinforce those areas of the outer cover which are affected by the propeller wash.

girder, walkway—The girder forming the support of a walkway through the keel or in other localities in a rigid or semirigid airship. (Fig. 4.)

gland—a short tube fitted to an envelope or gas bag in such a manner that a rope or line may slide through without leakage of gas or air. (Figs. 2 and 5.)

gland, manometer-tube—A gland fitted to the envelope of an aerostat to form a gas-tight connection for the tube leading to the manometer in the car. Same as "pressure-tube gland."

gland, pressure-tube—See GLAND, MANOMETER-TUBE.

glide—A descent with reference to the air at a normal angle of attack and without engine power sufficient for level flight in still air, the propeller thrust being replaced by a component of gravity along the line of flight. Also used as a verb.

glider—A form of aircraft similar to an airplane, but without a power plant.

goldbeater's-skin fabric—See FABRIC, GOLDBEATER'S-SKIN.

gondola—The car of an airship. This use of the word is borrowed from the Italian via the German. "Car" is to be preferred.

gore—The portion of the envelope of a balloon or airship included between two adjacent meridian seams.

grab line—See LINE, HANDLING.

grommet—A small ring of cord.

gross lift (airship)—See LIFT, GROSS (AIRSHIP)

ground angle—See ANGLE, LANDING.

ground cloth—See CLOTH, GROUND.

ground crew—See CREW, LANDING.

ground equipment—See GEAR, GROUND.

ground gear—See GEAR, GROUND.

ground speed—See SPEED, GROUND.

ground-speed meter—An instrument for measuring the speed of an aircraft relative to the ground. In present types of instruments some reference line in the instrument must first be set parallel to the apparent direction of motion of the aircraft with reference to the ground before the speed measurement is made. This is usually accomplished by the use of a drift meter, the adjustment of which automatically orients the ground-speed meter properly. Thus both the magnitude and direction of the motion of the aircraft with reference to the ground are obtained.

guy, yaw—See LINE, YAW.

gyroscopic turn indicator—See INDICATOR, GYROSCOPIC TURN.

handling line—See LINE, HANDLING.

hangar—A shelter for housing aircraft. More properly applied to heavier-than-air craft.

harness, mooring—A system of webbing bands, fitted over the top of the envelope of a balloon, to which are attached the mooring ropes. Usually found only in kite balloons or observation balloons. (Fig. 2.)

height, pressure—The altitude at which the gas cells of a rigid airship are full, or the gas bag of a nonrigid airship is completely full of gas.

helicopter—A form of aircraft whose sole support in the air is derived directly from the vertical component of the thrust produced by rotating airfoils.

hog—A distortion of an airship in which the longitudinal axis becomes convex upward so that both ends droop.

hood, gas-shaft—A hood, or cowl, located on the outer cover of a rigid airship at the outer end of a gas shaft. It is usually made of light wood and fabric and is faced to facilitate the escape of gas. Sometimes called "exhaust-gas hood."

In view of the possibility of confusion with the parts of an engine exhaust system, it is believed that "gas-shaft hood" is to be preferred. (Fig. 4.)

hood, maneuvering-valve—A hood, or cowl, located on the outer cover of a rigid airship just over a maneuvering valve. It is usually made of light wood or fabric and is faced to facilitate the escape of gas. (Fig. 4.)

hood, valve—The appliance, having the form of a hood or parasol which protects the valve of an airship or balloon against rain. Also called "valve cover" or "bonnet." (Figs. 2, 4, and 5.)

horn—A short lever attached to a control surface of an aircraft. For example, aileron horn, rudder horn, elevator horn. (Figs. 1, 3, 9, 10, 13, and 14.)

horsepower of an engine, maximum—The maximum horsepower which an engine can develop.

horsepower of an engine, rated—The average horsepower developed by an engine of a given type in passing the standard 50-hour endurance test.

hull (**airship**)—The main structure of a rigid airship, consisting of a covered elongated framework which incloses the gas cells and supports the cars and equipment. (Fig. 4.) May also be applied to the complete buoyant unit of any aerostat. In this latter sense sometimes called "gas bag."

hull (**seaplane**)—The portion of a flying boat which furnishes buoyancy when in contact with the surface of the water. It contains accommodations for the crew and passengers, usually incorporating the functions of a float and fuselage in one unit. (Fig. 9.)

impact pressure—See DYNAMIC (OR IMPACT) PRESSURE.

inclinometer—An instrument for indicating the attitude of an aircraft. Inclinometers are termed fore-and-aft, lateral, or universal, according as they indicate inclination on the vertical plane through the fore-and-aft axis, or in the vertical plane through the lateral axis, or in both planes, respectively.

inclinometer, absolute—An instrument which indicates the attitude of an aircraft with reference to the vertical. The indications of instruments of this type usually depend on gyroscopic action.

inclinometer, relative—An instrument which indicates the attitude of an aircraft with reference to apparent gravity, i. e., to the resultant of the acceleration of the aircraft and that due to gravity.

indicator, air-speed—See AIR-SPEED METER.

indicator, ballonet-fullness—An instrument for indicating the volume of air in a ballonet.

indicator, flight—An instrument in which a lateral inclinometer, a fore-and-aft inclinometer, and a turn indicator are combined to form a compact unit.

indicator, gyroscopic turn—A turn indicator dependent on gyroscopic action.

indicator, pitch—An instrument for indicating the existence of a pitching velocity of an aircraft. Cf. turn indicator.

indicator, static turn—A turn indicator actuated by the difference in pressure between static tubes mounted near the wing tips equidistant from the plane of symmetry and in a plane parallel to the lateral axis.

indicator, turn—An instrument for indicating the existence of an angular velocity of turn of an aircraft about the normal axis. In horizontal flight it indicates the presence of a yawing velocity. "Turn meter" is the term applied to certain types.

indraft (**inflow**)—The flow of air from in front of the propeller into the blades.

induced drag—See DRAG, INDUCED.

induction compass—See COMPASS, INDUCTION.

inflation—The act of filling a balloon or airship with gas.

inflation manifold—See MANIFOLD, INFLATION.

inflation net—See NET, INFLATION.

inflation sleeve—See SLEEVE, INFLATION.

inflation tube—See TUBE, INFLATION.

inflow—See INDRAFT.

inspection window—See WINDOW, INSPECTION.

intermediate longitudinal—See LONGITUDINAL, INTERMEDIATE.

intermediate transverse—See TRANSVERSE, INTERMEDIATE.

inverted engine—See ENGINE, INVERTED.

jackstay—A longitudinal rigging provided to maintain the correct distance between various parts on fittings on an aerostat.

keel (airship)—The assembly of members at the bottom of the hull of a semirigid or rigid airship which provides special strength to resist hogging and sagging and also serves to distribute the effect of concentrated loads along the hull. It may be a simple Gall's chain, as in some semirigids, or a very extensive structure inclosing the corridor, as in most rigids. (Figs. 4 and 5.)

king-post—The main compression member of a trussing system applied to support a single member subject to bending. (Figs. 4 and 6.)

kite—An aircraft heavier than air, restrained by a tow-line and sustained by the relative wind.

kite balloon—See BALLOON, KITE.

kymograph—An instrument for recording the angular oscillations of an aircraft in flight with respect to axes fixed in space. The reference direction is usually given by a gyroscope or a beam of sunlight.

laminated wood—See WOOD, LAMINATED.

landing angle—See ANGLE, LANDING.

landing crew—See CREW, LANDING.

landing field—A field of such a size and nature as to permit of aircraft landing and taking off in safety. It may or may not be part of an airport.

landing field, emergency—A locality, either of water or land, which is adapted for the landing and taking off of aircraft, but which is not equipped with facilities for shelter, supply, and repair of aircraft and is not used regularly for the receipt or discharge of passengers or cargo by air.

landing gear—The understructure which supports the weight of an aircraft when in contact with the surface of the land or water and reduces the shock on landing. There are five common types—boat type, float type, skid type, wheel type, and ski type. (Figs, 1, 6, 9, 10, and 14.) (Amphibian may be a combination of the float or boat type with wheels or skis.)

landing speed—See SPEED, LANDING.

landing T—A large symbol shaped like a capital T which is laid out on a landing field or on the top of a building to guide operators of aircraft in landing and taking off.

landing wire—See WIRE, LANDING.

landplane—An airplane designed to rise from and alight on the land. (Figs 1, 6, and 14.)

leading edge—The foremost edge of an airfoil or propeller blade. Also called "entering edge."

leak detector—An instrument which detects the presence of hydrogen and other light gases in the air, and which can be adapted to find leaks in a container inflated with such a gas.

left-hand engine—See ENGINE, LEFT-HAND.

left side (engine)—That side which, to an observer looking from the antipropeller end toward the propeller end, lies on the left-hand side.

lift—That component of the total air force on an aircraft or airfoil which is perpendicular to the relative wind and in the plane of symmetry. It must be specified whether this applies to a complete aircraft or to parts thereof. In the case of an airship, this is often called "dynamic lift." Its symbol is L.

The "absolute lift coefficient" is C_L as defined by the equation

$$C_L=\frac{L}{qS}$$

in which L is the lift, q is the impact pressure $(=\frac{1}{2}\rho V^2)$ and S is the effective area of the surface upon which the air force acts.

lift (of a gas)—The difference of density of air and the gas. Both supposed to be under the same conditions of pressure, temperature, etc.

lift, dynamic—The lift impressed on an aerostat by aerodynamic forces.

lift, gross (**airship**)—The lift obtained from a volume of buoyant gas equal to the nominal gas capacity of the aircraft. Obtained by multiplying the nominal gas capacity by the lift per unit volume of the gas used for inflation.

lift, static (**aerostat**)—The resultant upward force on an aerostat at rest obtained by multiplying the actual volume of the air displaced by the density of the air and subtracting the weight of the contained gas. (The volume of the air displaced, multiplied by the difference of density of the air and the contained gas.)

lift, useful (**airship**)—The lift available for carrying fuel, and oil, passengers, cargo, food, and drinking water, guns, ammunition, and bombs. Usually determined by deducting from the gross lift all fixed weights; certain allowances of ballast, fuel, and oil; water; spares and tools; crew and equipment. No standard has as yet been established.

lift wire—See WIRE, LIFT.

line, bow-steadying—See LINE, YAW.

line, grab—See LINE, HANDLING, and ROPE, DRAG.

line, handling—A line attached along the side of an airship for use in maneuvering near and on the ground. (Figs. 2, 3, 4, and 5.) Sometimes called "grab line."

line, main hauling—Same as MAIN MOORING LINE.

line, main mooring—The line dropped from the bow of an airship to be coupled to the mast main mooring line. (Fig. 4.)

line, mast bow-steadying—See LINE, MAST YAW.

line, mast main hauling—Same as MAST MAIN MOORING LINE.

line, mast main mooring—A line led from the main winch of a mooring mast through the mooring attachment at the top of the mast and carried out to a point on the ground well to leeward of the mast. The airship's main mooring line is attached to this line and the airship is hauled to the mast by means of the joined lines. Sometimes called "ground wire"—British.

line, mast yaw—One of the lines led from a winch at the base of the mooring mast through snatch blocks and carried out to leeward of the mast. The airship's yaw lines are attached to these lines. The snatch blocks are fixed to anchorages selected so that the joined lines tend to keep the airship into the wind and prevent her overriding the mast. These lines are also sometimes called "mast yaw guys" or "mast bow-steadying lines."

line, mooring—A line attached near the bow of an airship for securing it to the ground or to a mooring mast. (Figs. 3, 4, and 5.)

line, nose-steadying—See LINE, YAW, which is to be preferred.

line, sandbag—A rope extending along the line of suspension ropes or bridles of a kite balloon to which are hooked the sandbags used in mooring the balloon. The purpose is to prevent wear on the suspension cordage.

lines, control—The lines of wire and/or stranded cable leading from the control car or compartment to the various parts of an airship and operating (either through mechanisms or directly) the rudders, valves, etc., which control the speed, altitude, etc., of the airship.

line, suspension—A line either of cordage or metal, which supports the weight attached to the envelope of a balloon or airship. (Figs. 2, 3, 5, and 11.)

line, yaw—A line dropped from the bow of an airship, when mooring to the mast, to act as a steadying line to prevent yawing and overriding the mast. Also called "bow-steadying line" or "yaw guy." ("Side guy wire"—British.)

load:

dead—See WEIGHT, EMPTY.

full—Weight empty plus useful load. Also called "gross weight."

pay—That part of the useful load from which revenue is derived, viz., passengers and freight.

useful—The crew and passengers, oil, and fuel, ballast other than emergency, ordnance, and portable equipment.

load, basic—The load on an aircraft when it is at rest or in a condition of unaccelerated rectilinear flight. (For purposes of stress analysis.)

load, dynamic—Any load due to accelerations of an aircraft, and therefore proportional to its mass.

load factor—The ratio of any specified load on a member to the corresponding basic load. Generally applied to the ratio of the breaking load to a basic load.

load-ring—See RING, CONCENTRATION.

loading, power—The gross weight of an airplane, fully loaded, divided by the normal brake horsepower of the engine computed for air of standard density unless otherwise stated.

loading, wing—The gross weight of an airplane, fully loaded, divided by the area of the supporting surface. The area used in computing the wing loading should include ailerons, but not the stabilizer and elevators.

lobe—An air or gas inflated bag fitted at the stern of a kite balloon and acting as a fin or stabilizer to give it aerodynamic stability. (Fig. 2.)

logarithmic decrement—The natural logarithm of the ratio of two successive amplitudes in a damped harmonic motion. It is equal to the product λT, where λ is the coefficient appearing in the damping factor of damped harmonic motion and T is the period of the motion.

longeron—A fore-and-aft member of the framing of an airplane fuselage or nacelle, usually continuous across a number of points of support. (Fig. 1.)

longitudinal dihedral angle—See ANGLE, LONGITUDINAL DIHEDRAL.

longitudinal, intermediate—An intermediate longitudinal strength member of a rigid airship, which lies between two adjacent main longitudinals and is generally of lighter weight and/or smaller dimension than the main longitudinals. (Fig. 4.)

longitudinal, main—A main longitudinal strength member, of a rigid airship, which connects the various transverse frames. (Fig. 4.)

loop, mooring—See LOOP, SANDBAG.

loop, safety—A loop formed in a rip cord and attached to a securing patch by a breakable cord or a spring clip. It may be formed either inside the envelope and close to the rip panel or outside the envelope near the gland by which the rip cord passes through the envelope. Before the rip panel can be "pulled" the breakable cord must be broken or the clip opened. Accidental "pulling" is thus made unlikely, as the weight of the cord is easily carried by the breakable cord or spring clip.

loop, sandbag—A system of cordage loops on the envelope of a balloon for suspending sandbags. See also LINE, SANDBAG.

main hauling line—See LINE, MAIN MOORING.

main longitudinal—See LONGITUDINAL, MAIN.

main mooring line—See LINE, MAIN MOORING.

main mooring line, mast—See LINE, MAST MAIN MOORING.

main shear wire—See WIRE (AIRSHIP), MAIN SHEAR.

main supporting surface—See SURFACE, MAIN SUPPORTING.

main transverse—See TRANSVERSE, MAIN.

maneuverability—That quality in an aircraft which makes it possible for the pilot to change its attitude rapidly.

maneuvering valve—See VALVE, MANEUVERING.

maneuvering-valve hood—See HOOD, MANEUVERING-VALVE.

manhole, appendix—An appendix of large diameter and usually rather short. It is used more for access than for inflation or deflation. (Fig. 2.)

manifold, inflation—A metal or fabric connection with numerous inlets which permits the passage of gas at the same time from a number of sources (either cylinders or gas holders) to the main inflation tube.

manometer pressure—See PRESSURE, MANOMETER (AEROSTAT).

manometer-tube gland—See GLAND, MANOMETER-TUBE.

mast bow-steadying line—See LINES, MAST YAW.

mast main hauling line—See LINE, MAST MAIN MOORING.

mast main mooring line—See LINE, MAST MAIN MOORING.

mast, mooring—A mast or tower at the top of which there is mounted a fitting, so that the bow of an airship may be secured. It is usually provided with a ladder or staircase and a platform at the top, so that crew and passengers may enter or leave the airship, and also with piping for the supply of fuel, gas, and water. Sometimes called "mooring tower."

mast yaw line—See LINE, MAST YAW.

meter, air-speed—See AIR-SPEED METER.

meter, ground-speed—See GROUND-SPEED METER.

meter, superheat—An instrument for measuring the difference in temperature between the gas in a gas container of a lighter-than-air craft and the surrounding air.

minimum gliding angle—See ANGLE, MINIMUM GLIDING.

minimum speed—See SPEED, MINIMUM.

monocoque fuselage—See FUSELAGE, MONOCOQUE.

monoplane—An airplane which has but one main supporting surface, sometimes divided into two parts by the fuselage. (Fig. 6.)

mooring band—See BAND, MOORING.

mooring cone—See CONE, MOORING.

mooring-cone outrigger—See OUTRIGGER, MOORING-CONE.

mooring drag—See DRAG, MOORING.

mooring harness—See HARNESS, MOORING.

mooring line—See LINE, MOORING.

mooring loop—See LOOP, SANDBAG.

mooring mast—See MAST, MOORING.

mooring ring—See RING, MOORING.

mooring rope—See ROPE, MOORING.

mooring, three-point—A system of mooring an airship. It consists primarily of three lines running from a mooring ring (or point) on the airship to three points on the ground. These points are usually at the vertices of an equilateral triangle. The lines may be secured to anchorages at the points, or run over snatch blocks and to equalizing gear. The endeavor is to moor the airship in such a manner that the dynamic lift, due to the relative wind, shall keep the airship at a constant height from the ground. May be considered as a substitute for a mooring mast, usually an emergency substitute.

mooring tower—See MAST, MOORING.

multiplane—An airplane with two or more main supporting surfaces placed one above another.

nacelle—An inclosed shelter for passengers or for a power plant. A nacelle is usually shorter than a fuselage, and does not carry the tail unit. (Fig. 14.)

net:

- **free-balloon**—A rigging made of ropes and twine shaped to the upper surface of the envelope, which supports the weight of the basket, etc., and distributes the load over the entire upper surface of the envelope. (Fig. 11.)
- **gas-cell (rigid airship)**—A netting of cord of small mesh which is intended to assist the fabric of the gas cells in transmitting gas force to a wire netting of coarser mesh and to the longitudinals, both being fitted between the longitudinals. It may be compared to the net of a free balloon. Sometimes called "gas-cell netting" or "cord netting." (Fig. 4.)
- **inflation**—A rectangular net of cordage used to restrain the envelope of a kite balloon or airship during inflation. Also applied to a free-balloon net designed to be removed after inflation.

netting cord—See NET, GAS CELL (RIGID AIRSHIP).

netting wire—See WIRE (AIRSHIP), NETTING.

nominal gas capacity—See CAPACITY, NOMINAL GAS.

nonrigid airship—See AIRSHIP, NONRIGID.

nose (airship)—Sometimes used for bow.

nose batten—See STIFFENER, BOW.

nose cap—See CAP, BOW, which is to be preferred.

nose-heavy—The condition of an airplane in normal flight when the distribution of forces is such that, if the longitudinal controls were released, the nose would drop.

nose-heavy (airship)—See BOW-HEAVY.

nose-steadying line—See LINE, YAW.

nozzle, pressure—An instrument which, in combination with a gauge, is used to measure the indicated speed of an aircraft relative to the air. It may be a Pitot-static or a Venturi tube, or a combination of a Pitot tube and a Venturi tube.

nurse balloon—See BALLOON, CONSTANT PRESSURE.

nursing tube—See TUBE, SUPPLY.

observation balloon—See BALLOON, OBSERVATION.

observation platform—See PLATFORM, OBSERVATION.

optical altimeter—See ALTIMETER, OPTICAL.

ornithopter—A form of aircraft heavier than air, deriving its chief support and propelling force from flapping wings.

oscillation, phugoid—A long-period oscillation characteristic of the disturbed longitudinal motion of an aircraft. This is referred to when it is said that an aircraft "hunts."

oscillation, stable—An oscillation whose amplitude does not increase.

oscillation, unstable—An oscillation whose amplitude increases continuously until an attitude is reached from which there is no tendency to return toward the original attitude, the motion becoming a steady divergence.

outer cover—See COVER, OUTER.

outrigger, mooring-cone—The member, usually tubular, which supports the mooring cone at the bow of the airship. Sometimes referred to as "mooring spindle." (Fig. 4.)

over-all length—The distance from the extreme front to the extreme rear of an aircraft, including the propeller and the tail unit.

overhang—Used in two senses. (1) One-half of the difference in span of any two main supporting surfaces of an airplane. The overhang is positive when the upper of the two main supporting surfaces has the larger span. (Fig. 1.) (2) The distance from the outer strut attachment to the tip of the wings.

overhead suspension—See SUSPENSION, OVERHEAD.

pancake, to—To level off an airplane at a greater altitude than normal in a landing, thus causing it to stall and to descend on a steeply inclined path with the wings at a very large angle of attack and without appreciable bank.

panel (aerostat)—The unit piece of fabric of which the envelope or outer cover of an aerostat is made. Panels may be assembled into sections, gores, or rings, according to the method of manufacture followed.

In rigid airships the area bounded by two adjacent longitudinals and two adjacent transverses is often referred to as a "panel." This is a structural panel and the expression is borrowed from structural engineers.

panel, rip—A strip of fabric inserted or fitted in the upper part of the envelope of a balloon or semirigid or nonrigid airship which is torn or ripped open when immediate deflation is desired. (Figs. 2 and 3.)

panel (wing parts)—Where a wing surface comprises several units of construction, these units are designated as panels.

parasite resistance—See DRAG.

patch—A strengthened or reinforced flap or fabric of special shape and construction, which is cemented to the envelope or gas cell. It usually forms an anchor by which some portion of the structure may be attached to the envelope, or by which the positioning lines controlling the gas cell, may be attached to the cell. (Fig. 12.)

patch, chafing—A patch of fabric secured to the envelope of an aerostat to protect it from abrasion.

patch, channel—A channel-shaped fabric-fitting secured to the envelope of an aerostat to allow a rod or spar to be laced to the envelope.

patch, finger—A special form of patch having extensions or "fingers" extending out from the central portion. The "fingers" may be of tape, frayed out rope, or fabric. Their function is to distribute the load more widely to the fabric of the envelope or gas cells. (Fig. 12.)

patch, suspension—A patch, secured to the envelope or to a gas cell of an aerostat, to which a suspension line may be attached. (Fig. 12.)

pay load—See LOAD, PAY.

pendant, sighting.—A vertical wire on center line and forward of the control car of an airship, used as a mark in steering, to assist in determining wind direction.

performance testing—See TESTING, PERFORMANCE.

period—The time taken for a complete oscillation.

permeability—The measure of the rate of diffusion of gas through intact balloon fabric; usually expressed in liters of hydrogen per square meter of fabric per 24 hours, under standard conditions of pressure and temperature.

phugoid oscillation—See OSCILLATION, PHUGOID.

pigmented dope—See DOPE (PIGMENTED).

pilot—An operator of aircraft. This term is applied regardless of the sex of the operator.

pilot balloon—See BALLOON, PILOT.

pitch, angle of—See ANGLE OF PITCH.

pitch indicator—See INDICATOR, PITCH.

pitch of a propeller:

- **effective**—The distance which an aircraft advances along its flight path for one revolution of the propeller. Its symbol is p_e.
- **geometrical**—The distance which an element of a propeller would advance in one revolution, if it were moving along a helix of slope equal to its blade angle.
- **mean geometrical**—The mean of the geometrical pitches of the several elements. Its symbol is p_g.
- **standard**—The geometrical pitch taken at two-thirds of the radius. Also called "nominal pitch." Its symbol is p_s.
- **zero thrust**—The distance which a propeller would have to advance in one revolution in order that there might be no thrust. Also called "experimental mean pitch." Its symbol is p_v.
- **zero torque**—The distance which a propeller would have to advance in one revolution in order that the torque might be zero. Its symbol is p_a.

pitch ratio—The ratio of the pitch (geometrical, unless otherwise stated) to the diameter p/D.

pitch speed—The product of the mean geometrical pitch by the number of revolutions of the propeller in unit time—i. e., the speed the aircraft would make if there were no slip.

Pitot tube—A cylindrical tube with an open end which is pointed upstream (i. e., so that the air meets the instrument head-on or is met head-on by the instrument). When the aircraft is flying less than about 200 miles per hour, the instrument measures the impact pressure. When used on aircraft, it is usually associated either with a closed coaxial tube surrounding it or with a closed tube placed near it and parallel to it, the combination being termed a Pitot-static tube. The associated tube has perforations in its side so that it is subjected to static pressure, as distinct from impact pressure. The speed of the fluid can be determined from the difference between the impact pressure and the static pressure as read by a suitable gauge. (Fig. 7.) In common terminology the Pitot-static combination, as above, is often termed simply a Pitot tube or Pitot.

platform, observation—A platform or small deck fitted on the top of an airship and used as a post for a lookout and defense or as a place from which to make observations used in navigating the airship. (Figs. 4 and 5.)

plywood—A product formed by gluing together two or more layers of veneer. The alternate plies are usually placed with grain at right angles to the adjacent plies.

pontoon (**now obsolete**)—See FLOAT.

power loading—See LOADING, POWER.

pressure alarm—See ALARM, GAS-CELL.

pressure, dynamic—See DYNAMIC (OR IMPACT) PRESSURE.

pressure flap—See FLAP, PRESSURE.

pressure height—See HEIGHT, PRESSURE.

pressure, manometer (**aerostat**)—The excess of pressure inside the envelope of an aerostat over the atmospheric pressure at a standard reference point. The point of reference for the excess of pressure is usually the bottom of the envelope or gas cell for airships and the level of the basket for kite balloons.

pressure nozzle—See NOZZLE, PRESSURE.

pressure-relief vent—See VENT, PRESSURE-RELIEF.

pressure tube—See TUBE, PRESSURE.

pressure-tube gland—See GLAND, MANOMETER-TUBE.

profile—See AIRFOIL SECTION (OR PROFILE).

profile drag—See DRAG.

proofing—Material incorporated in the fabric of an aerostat at the time of manufacture to increase its resistance to the weather and/or to prevent the passage of gas (or decrease its permeability).

propaganda balloon—See BALLOON, PROPAGANDA.

propeller:

adjustable pitch—A propeller whose blades are so attached to the hub that they may be set to any desired pitch when the propeller is stationary.

controllable pitch or variable pitch—A propeller whose blades are so mounted that they may be turned about their axis to any desired pitch while the propeller is in rotation.

propeller area, projected—The total area in the plane perpendicular to the propeller shaft swept by the propeller, excepting the portion covered by the boss and that swept by the root of the blade. This portion is usually taken as extending 0.2 of the maximum radius from the axis of the shaft.

propeller blade—See BLADE FACE; BLADE BACK; BLADE-WIDTH RATIO. (Fig. 1.)

propeller-blade angle—See ANGLE, PROPELLER-BLADE.

propeller-blade area—The area of the blade face, exclusive of the boss and the root, i. e., of a portion which is usually taken as extending 0.2 of the maximum radius from the axis of the shaft.

propeller boss—The central portion of a propeller in which the hub is formed or mounted. (Fig. 1.)

propeller-camber ratio—The ratio of the maximum thickness of a propeller section to its chord.

propeller-disk area, total—The total area swept by a propeller, i. e., the area of a circle having a diameter equal to the propeller diameter.

propeller efficiency—The ratio of thrust power to power input of a propeller. Its symbol is η.

propeller hub—The metal fitting inserted or incorporated in or with a propeller for the purpose of mounting it on the propeller or engine shaft. (Fig. 1.)

propeller interference—The amount by which the torque and thrust of a propeller are changed by the modification of the air flow in the slip stream produced by bodies placed near the propeller, such as engine, radiator, etc.

propeller-load curve—A curve representing the engine power necessary to drive any given propeller at various speeds. The power required varies approximately as the cube of the speed in R. P. M., provided the ratio $\frac{V}{ND}$ remains constant.

propeller pitch—See PITCH OF A PROPELLER.

propeller, pusher—A propeller mounted to the rear of the engine or propeller shaft. (It is usually behind the wing cell or nacelle.) (Figs. 9 and 14.)

propeller rake—The mean angle which the line joining the centroids of the sections of a propeller blade makes with a plane perpendicular to the axis.

propeller reinforcing girder—See GIRDER, PROPELLER REINFORCING.

propeller root—That part of the propeller blade near the boss. (Fig. 1.)

propeller section—A cross section of a propeller blade made at any point by a plane parallel to the axis of rotation of the propeller and tangent at the centroid of the section to an arc drawn with the axis of rotation as its center.

propeller thrust—The component parallel to the propeller axis of the total air force on the propeller. Its symbol is T.

propeller torque—The moment applied to the propeller by the engine shaft. Its symbol is Q.

propeller, tractor—A propeller mounted on the forward end of the engine or propeller shaft. (It is usually forward of the fuselage or wing nacelle.) (Figs. 1, 6, and 10.)

propeller-width ratio, total—The product of blade-width ratio at the point of maximum blade width by number of blades.

propulsive efficiency—The ratio of the product of effective thrust and flight speed to the actual power input to the propeller as mounted on the airplane, consistent units being used throughout.

purity (of gas)—The ratio of the pressure of the hydrogen (or other aerostatic gas) in the container to the total pressure due to all the contained gases.

pusher airplane—See AIRPLANE, PUSHER.

pusher propeller—See PROPELLER, PUSHER.

quadrant—The operating lever, made on the arc of a circle, of a control surface of an airship, e. g., rudder quadrant, elevator quadrant. (Fig. 4.)

quadruplane—An airplane with four main supporting surfaces, placed one above another.

race rotation—The rotation, produced by the action of the propeller, of the stream of air passing through or influenced by the propeller.

radial engine—See ENGINE, RADIAL.

radial wire—See WIRE (AIRSHIP), RADIAL.

rail, docking—A rail or guide, constructed on the landing field and extending into the shed, which supplies a means for holding the lateral pull of an airship's docking or handling lines. The pull is transmitted to the rails from wheeled cars or trolleys which are fitted on or in the rails. Usually two rails are fitted at the greatest distance apart which will permit them to be run into the shed.

rake, propeller—See PROPELLER RAKE.

ram—The combination of tubes and springs which is mounted in gimbals at the top of a mooring mast. It consists of an outer tube which carries the gimbal mounting and within which slides an inner tube. The upper end of the inner tube carries the hollow cone which receives the airship's mooring cone and which is fitted to revolve freely. The inner tube can slide down into the outer tube and compress heavy springs, thus easing the shock when the mooring is made.

range at economic speed—The maximum distance a given aircraft can cover while cruising at the most economical speed and altitude at all stages of the flight.

range at full speed—The maximum distance a given aircraft can cover at full speed at sea level.

rate of climb—The vertical component of the air speed of an aircraft, i. e., its vertical velocity with reference to the air.

recorder, flight—An instrument for recording certain elements of the performance of an aircraft.

relative inclinometer—See INCLINOMETER, RELATIVE.

relative wind—See WIND, RELATIVE.

resistance derivatives—Quantities expressing the variation of the forces and moments on aircraft due to disturbance of steady motion. They form the experimental basis of the theory of stability, and from them the periods and damping factors of aircraft can be calculated. In the general case there are 18 translatory and 18 rotary derivatives.

lateral—Resistance derivatives expressing the variation of moments and forces due to small changes in the lateral, yawing, and rolling velocities.

longitudinal—Resistance derivatives expressing the variation of moments and forces due to small changes in the longitudinal, normal, and pitching velocities.

rotary—Resistance derivatives expressing the variation of moments and forces due to small changes in the rotational velocities of the aircraft.

translatory—Resistance derivatives expressing the variation of moments and forces due to small changes in the translational velocities of the aircraft.

restoring moment—See RIGHTING MOMENT.

reverse turn—See TURN, REVERSE.

revolutions, maximum—The number of revolutions per minute corresponding to the maximum horsepower.

revolutions, rated—The number of revolutions corresponding to the rated horsepower.

Reynolds Number—A name given the fraction $\rho \frac{Vl}{\mu}$ in which

ρ is the density of the fluid;
V is the relative velocity of the fluid;
l is the linear dimension of the body;
μ is the coefficient of viscosity of the fluid.

rigger—One who is employed in assembling and aligning aircraft.

rigging (aerostat)—The attachment and adjustment of the car, rudders, valves, controls, etc., of an airship.

rigging, (airplane)—The assembling, adjusting, and aligning of the parts of an airplane.

right-hand engine—See ENGINE, RIGHT-HAND.

righting moment (or restoring moment)—A moment which tends to restore an aircraft to its previous attitude after any small rotational displacement.

right side (engine)—That side which, to an observer looking from the antipropeller end toward the propeller end, lies on the right-hand side.

rigid airship—See AIRSHIP, RIGID.

ring, concentration:

airship—A ring to which several rigging lines are led from the envelope and from which one or more lines also lead to the car.

free balloon—A ring to which are attached the ropes suspending the basket and to which the net is also secured. Sometimes called "load ring." (Fig. 11.)

ring, load—See RING, CONCENTRATION (FREE BALLOON).

ring, mooring—A metallic ring suspended from one of the forward frames of a rigid airship by wire lines and used for mooring. The vertex of a "three-point mooring" is attached to this ring.

rip-cord—See CORD, RIP.

rip-panel—See PANEL, RIP.

roll—A maneuver in which a complete revolution about the longitudinal axis is made, the horizontal direction of flight being approximately maintained.

roll, angle of—See ANGLE OF ROLL.

rope, drag—A long rope which can be hung overboard from a balloon so as to act as a brake and a variable ballast in making a landing. Same as "trail rope" or "guide rope." On airships a similar rope or ropes is used as a haul-down or mooring line by the landing crew. It is usually larger and longer than a regular handling line. Sometimes called "grab line."

rope, mooring—A line attached to a balloon or airship for use in securing it to the ground. It may serve the purpose of a "handling line," or vice versa. (Fig. 2.)

rope, trail—See ROPE, DRAG.

rotary engine—See ENGINE, ROTARY.

rudder—A movable auxiliary airfoil, the function of which is to impress a yawing moment on the aircraft in normal flight. It is usually located at the rear of an aircraft. (Figs. 1, 9, 10, and 14.)

rudder (**airship**)—A hinged or pivoted surface, usually attached to a fin at the after end of an airship. When operated by the pilot it produces a yawing moment and gives directional control in the plane at right angles to the axis about which it is hinged or pivoted. (Figs. 3, 4, and 5.)

rudder angle—See ANGLE, RUDDER.

rudder bar—The foot bar by means of which the control cables leading to the rudder are operated. (Fig. 1.)

rudder torque—The twisting moment exerted by the rudder on the fuselage. The product of the rudder area by the distance from its center of area to the axis of the fuselage may be used as a relative measure of rudder torque.

safety, factor of—See FACTOR OF SAFETY.

safety loop—See LOOP, SAFETY.

sag—A distortion of an airship in which the longitudinal axis becomes concave upward so tha both ends rise.

sandbag line—See LINE, SANDBAG.

sea anchor—See ANCHOR, SEA.

seaplane—Any airplane designed to rise from and alight on the water. This general term applies to both boat and float types, though the boat type is usually designated as a "flying boat." (Figs. 9 and 10.)

secondary shear wire—See WIRE (AIRSHIP), SECONDARY SHEAR.

semirigid airship—See AIRSHIP, SEMIRIGID.

service tank—See TANK, SERVICE.

shaft, climbing—An access shaft fitted with a ladder and leading from the bottom to the top of an airship hull. This may be fitted in an airship of any type. (Figs. 4 and 5.)

shaft, gas—A duct or shaft leading from the bottom of the gas cells to the outer cover of an airship. It affords a clear passage for the escape of gases which have accumulated in the gangway or corridor or which are discharged from the valves at the bottom of the cells.. It usually consists of light wooden hoops or frames spaced at intervals on cords or wires and is covered by a netting. It prevents the gas cells from closing hard against one another and thus keeps the passage open. Sometimes called "gas trunk," "exhaust-gas shaft," or "trunk."

In view of the possibility of confusion with parts of an engine-exhaust system, it is believed that "gas shaft" or "trunk" is to be preferred. (Fig. 4.)

sheathing—See TIPPING (PROPELLER).

shed—A shelter for housing airships.

ship—Slang for an airplane. In view of the confusion with "airship" it should not be used.

shipplane—A landplane designed to rise from and alight on the deck of a ship.

shock absorber—A device incorporated in the landing gear of an aircraft to reduce the shock imposed on the structure when alighting or taking off.

Shock absorbing devices are usually interposed between the main structure and the wheels, floats, skis, or tail skids, to secure resiliency in landing and taxying. (Fig. 1.)

shore—A structural member for supporting the structure of a rigid or semirigid airship during building or docking, used in conjunction with (or without) a cradle.

side car—See CAR, WING.

side slipping—Flight in which the lateral axis is inclined and the airplane has a component of velocity in the direction of the lower end of the lateral axis. When it occurs in connection with a turn, it is the opposite of skidding. (q. v.)

sighting pendant—See PENDANT, SIGHTING.

skid—A runner used as a member of the landing gear and designed to aid the aircraft in landing or taxying.

tail skid—A skid used to support the tail when in contact with the ground. (Figs. 1, 6 and 14.)

wing skid—A skid placed near the wing tip and designed to protect the wing from contact with the ground. (Fig. 1.)

skidding—Sliding sidewise away from the center of curvature when turning. It is usually caused by banking insufficiently, and is the opposite of side slipping. (q. v.)

skid fin—A fore-and-aft vertical surface, usually placed above the upper wing, designed to provide vertical keel surface and so to increase lateral stability. (Figs. 9 and 10.)

skin friction—The tangential component of the fluid force at a point on a surface.

sky writing—The act of emitting from an aircraft a trail of smoke or other visible substance. the flight of the aircraft being so directed as to cause the trail to assume the form of letters or symbols.

sleeve, conical—A cone-shaped fabric, fitting in a bag or cell through which a line passes. It provides a gas-tight connection of the bag or cell to the line and yet permits both some degree of freedom to move.

sleeve, deflation—Generally a sleeve or appendix made of fabric provided for the special purpose of facilitating the deflation of an aerostat. Also applied to the sleeve or appendix fitted in the lower lobe of a kite balloon and used to permit the rapid escape of air in the lobes when the balloon is hauled down. (Fig. 2.)

sleeve, filling—See SLEEVE, INFLATION.

sleeve, inflation (or sleeve, filling)—A tubular fabric attachment to an envelope or gas bag, serving as a lead for the inflation tube. (Figs. 3 and 5.)

slip—The difference between the mean geometrical pitch and the effective pitch. Slip may be expressed as a percentage of the mean geometrical pitch or as a linear dimension.

slip fuel tank—See TANK, SLIP FUEL.

slip function—The ratio of speed of advance through the undisturbed air to the product of propeller diameter by the number of revolutions in unit time, i. e., $\frac{V}{N\,D}$. The slip function is the primary factor controlling propeller performance. It is π times the ratio of forward speed to the tip speed of the propeller.

slip stream—The stream of air driven astern by the propeller. (The indraft is sometimes included also.)

snatch-block anchorage—See ANCHORAGE, SNATCH-BLOCK.

soar—To perform sustained free flight without self-propulsion; it is called "up-current soaring" if performed in ascending air; "dynamic soaring" in other cases.

sounding balloon—See BALLOON, SOUNDING.

sound-ranging altimeter—See ALTIMETER, SOUND-RANGING.

span (airfoil)—The lateral dimension of an airfoil, i. e., its dimension perpendicular to its chord. Its symbol is b.

span (airplane)—The maximum distance measured parallel to the lateral axis from tip to tip of an airplane inclusive of ailerons. (Fig. 1.)

spar—See WING SPAR.

specific fuel (or oil) consumption—See FUEL (OR OIL) CONSUMPTION, SPECIFIC.

speed, critical—The lowest speed of an aircraft at which control can be maintained.

speed, economic—The speed at which the fuel consumption, per unit of distance covered in still air, is a minimum.

speed, ground—The horizontal component of the velocity of an aircraft relative to the earth.

speed, landing—The minimum speed at which an airplane can maintain itself in level flight and still be under adequate control.

speed, minimum—The lowest steady speed which can be maintained by an airplane in level flight at an altitude large in comparison with the dimensions of the wings, with any throttle setting whatever.

spin—A maneuver consisting of a combination of roll and yaw, with the longitudinal axis of the airplane inclined steeply downward. The airplane descends in a helix of large pitch and very small radius, the upper side of the airplane being on the inside of the helix, and the angle of attack on the inner wing being maintained at an extremely large value.

spindle, mooring—See OUTRIGGER, MOORING CONE.

spinner—A fairing of approximately conical or paraboloidal form, which is fitted coaxially with the propeller boss and revolves with the propeller. (Fig. 1.)

spiral—A maneuver in which an airplane descends in a helix of small pitch and large radius, the angle of attack being within the normal range of flight angles.

spiral instability—See STABILITY.

stability—That property of a body which causes it, when disturbed from a condition of equilibrium or steady motion, to develop forces or moments which tend to restore the body to its original condition.

- **automatic**—Stability dependent upon movable control surfaces automatically operated by mechanical means.
- **inherent**—Stability of an aircraft due solely to the disposition and arrangement of its fixed parts, i. e., that property which causes it, when disturbed, to return to its normal attitude of flight without the use of controls or the interposition of any mechanical devices.
- **static**—Stability of such a character that, if the airplane is displaced slightly from its normal attitude by rotation about an axis through its center of gravity (as may be done in wind-tunnel experiments), moments come into play which tend to return the airplane toward its original attitude.
- **dynamic**—Stability of such a character that, if the airplane is displaced from steady motion in flight, it tends to return to that steady state of motion, the oscillations due to restoring moments being damped out.

  In a general way, the difference between static stability and dynamic stability is that the former depends on restoring moments alone, while the latter includes the action of damping factors.
- **longitudinal**—Stability with reference to disturbances in the plane of symmetry, i. e., disturbances involving pitching and variation of the longitudinal and normal velocities
- **directional**—Stability with reference to rotations about the normal axis, i. e., an airplane possesses directional stability in its simplest form if a restoring moment comes into action when it is given a small angle of yaw. Owing to symmetry, directional stability is closely associated with lateral stability.
- **lateral**—Stability with reference to disturbances involving rolling, yawing, or side slipping, i. e., disturbances in which the position of the plane of symmetry of the aircraft is affected.
- **spiral instability**—A type of instability inherent in certain airplanes which becomes evident when the airplane, as a result of a yaw, assumes too great a bank and side slips; the bank continues to increase and the radius of the turn to decrease.

stabilizer—A normally fixed airfoil whose function is to lessen the pitching motion. It is usually located at the rear of an aircraft and is approximately parallel to the plane of the longitudinal and lateral axes. Also called "tail plane."

stabilizer (aerostat)—Same as FIN. The lobes of a kite balloon are sometimes referred to as stabilizers. (Figs. 1, 2, 3, 4, 5, 6, 9, 10, 13, and 14.)

stabilizer, mechanical—A mechanical device to prevent an aircraft from departing from a condition of steady motion, or, in case such a motion is disturbed, to restore it to its steady state. Includes gyroscopic stabilizers, pendulum stabilizers, inertia stabilizers, etc.

stabilizer setting, angle of—See ANGLE OF STABILIZER SETTING.

stable oscillation—See OSCILLATION, STABLE.

stagger—The amount of advance of the leading edge of an upper wing of a biplane, triplane, or multiplane over that of a lower, expressed either as a percentage of gap or in degrees of the angle whose tangent is the percentage just referred to. It is considered positive when the upper wing is forward and is measured from the leading edge of the upper wing along its chord to the point of intersection of this chord with a line drawn perpendicular to the chord of the upper wing at the leading edge of the lower wing, all lines being drawn in a plane parallel to the plane of symmetry. (Fig. 1.)

stall—The condition of an airplane when from any cause it has lost the air speed necessary for support or control.

static ceiling—See CEILING, STATIC.

static lift—See LIFT, STATIC (AEROSTAT).

static thrust—See THRUST, STATIC.

static trim—See TRIM, STATIC.

static turn indicator—See INDICATOR, STATIC TURN.

station, airship—The complete assembly of sheds, masts, gas plants, shops, landing fields, and related equipment required to operate airships and supply their needs. A station may include all or a part of the items enumerated. The base from which airships are operated.

statoscope—An instrument for detecting minute changes of altitude of an aircraft. The indications of the instrument usually depend on small changes of the static pressure of the air.

stay—A wire or other tension member; for example, the stays of the wing and body trussing. (Fig. 1.)

step—A break in the form of the bottom of a float or hull designed to reduce resistance when under way by rapidly reducing the wetted surfaces as speed increases. It also serves to eliminate suction effects.

stern-droop—A deformation of an airship in which its longitudinal axis bends downward at the after end.

stern framing—See FRAMING, STERN.

stern-heavy—The condition in which, in normal flight, the after end of an airship tends to sink and which requires correction by means of the horizontal controls. In this condition an airship is said to "trim by the stern." It may be due to either aerodynamic or static conditions, or to both.

stiffener, bow—A rigid member attached to the bow of a nonrigid or semirigid envelope to reinforce it against the pressure caused by the motion of the airship. Sometimes called "nose stiffener" or "nose batten." (Figs. 3 and 5.)

streamline—The path of a small portion of a fluid relative to a solid body with respect to which the fluid is moving. The term is commonly used only of such flows as are not eddying, but the distinction should be made clear by the context.

streamline flow—Steady flow past a solid body, i. e., a flow in which the direction at every point is independent of time.

streamline form—A solid body which produces approximately streamline flow.

stresses, breathing—Stresses produced in an aerostat by breathing. Of importance in the envelope and keel of a semirigid airship due to the interaction of envelope and keel when the envelope "breathes."

strip, drip—See FLAP, DRIP.

structural drag—See DRAG.

strut—A compression member of a truss frame. For instance, the vertical members of the wing truss of a biplane (interplane struts) and the short vertical and horizontal members separating the longerons (q. v.) in the fuselage. (Fig. 1.)

strut, drag—A fore-and-aft compression member of the internal bracing system of a wing. (Figs. 1 and 15.)

supercharged engine—See ENGINE, SUPERCHARGED.

supercharger—A mechanical device for supplying the engine with a greater weight of charge than would normally be induced at the prevailing atmospheric pressure and temperature.

centrifugal type—A supercharging device equipped with one or more rotating impellers generating centrifugal force which is utilized for the compression and the transmission of the air against resistance.

positive-driven type—A supercharger driven at a fixed speed ratio from the engine shaft by gears or other positive means.

rotary-blower type—A supercharging device comprising one or more relatively slow-speed rotors revolving in a stationary case in such a way as to provide a positive displacement.

turbo type—A supercharger driven by a turbine operated by the exhaust gases from the engine.

superheat—The amount by which the temperature of the gas in the envelope or gas cells of an aerostat is higher than the temperature of the surrounding air. If the contained gas has a lower temperature, the superheat is said to be negative.

superheat meter—See METER, SUPERHEAT.

supply balloon—See BALLOON, SUPPLY.

supply tube—See TUBE, SUPPLY.

supporting surface, main—See SURFACE, MAIN SUPPORTING.

surface, control—A movable airfoil designed to be rotated or otherwise moved by the pilot in order to change the attitude of the airplane or airship.

surface, fixed—See FIN.

surface, main supporting—A set of wings, extending on the same general level from tip to tip of an airplane; e. g., a triplane has three main supporting surfaces. The main supporting surfaces include the ailerons, but no other surfaces intended primarily for control or stabilizing purposes.

suspension band—See BAND, SUSPENSION.

suspension-bar—See BAR, SUSPENSION.

suspension line—See LINE, SUSPENSION.

suspension, overhead—A line leading from the roof of an airship shed and arranged to sustain the whole or a part of the weight of the structure of an airship when it is docked.

suspension patch—See PATCH, SUSPENSION.

suspension winch—The rigging by means of which the lift and drag of a kite balloon is transmitted from the envelope to the towing or traction cable. (Fig. 2.)

sweep back—The acute angle between the lateral axis of an airplane and the projection of the axis of the wing on the plane which includes the lateral and longitudinal axes. (Fig. 1.) (The axis of a wing is a line through the centroids of the section of the wing.)

tail (airship)—Sometimes used for stern.

tail boom—A spar or outrigger connecting the tail surfaces and main supporting surfaces (Fig. 14.)

tail-droop—See STERN-DROOP.

tail group (or tail unit)—The stabilizing and control surfaces at the rear end of an aircraft, including stabilizer, fin, rudder, and elevator. (Also called "empennage.")

tail-heavy—In a heavier-than-air craft, the condition in which in normal flight, the tail sinks if the longitudinal control is released, i. e., the condition in which the pilot has to exert a push on the control stick to keep the given attitude.

tail-heavy (airship)—See STERN-HEAVY.

tail plane—See STABILIZER.

tail skid—See SKID.

tail slide—The backward and downward motion, tail first, which certain airplanes may be made to take momentarily after having been brought into a stalling position by a steep climb

tandem airplane—See AIRPLANE, TANDEM.

tank, fixed fuel—A fuel tank which is not intended or fitted to be dropped, as "slip" tanks are.

tank, service—A fixed fuel tank near each power unit, into which fuel from other tanks is pumped and from which the fuel supplying the engines is drawn.

tank, slip fuel—A fuel tank which is provided with a device permitting the quick dropping of the tank and contents as a whole in case of an emergency. Fitted on both airships and airplanes.

taxi—To run an airplane over the ground, or a seaplane on the surface of water under its own power.

testing, performance—The process of determining performance characteristics.

thermograph—An instrument for recording temperature.

thimble—A grooved ring of circular, pear-, or heart-shaped form, generally of metal, which is inserted in the eye of a rope or wire to prevent chafing or deformation of the eye.

three-point mooring—See MOORING, THREE-POINT.

thrust, effective—The net driving force delivered by a propeller when mounted on an airplane, i. e., the actual thrust given by the propeller, as mounted on the airplane, minus any increase of resistance of the airplane produced by the action of the propeller.

thrust face—See BLADE FACE.

thrust, static—The thrust developed by a propeller when rotating at a fixed point.

tipping (propeller)—A sheet-metal (or equivalent) protective covering of the blade of a propeller near the tip, extended a short distance along the trailing edge and a considerable distance along the leading edge. (Fig. 1.)

toggle—A short crossbar of wood or metal which is fitted at the end of a rope. The rope passes around the mid length of the bar in a shouldered groove. By slipping it through an eye in the end of another rope, the two lengths of rope can be quickly connected or disconnected. (Fig. 2.)

topping up—The operation of filling up with gas an already partially full aerostat. Also applied to a similar operation with fuel tanks. Incorrectly called "nursing."

total propeller-width ratio—See PROPELLER-WIDTH RATIO, TOTAL.

tower, mooring—See MAST, MOORING.

tractor airplane—See AIRPLANE, TRACTOR.

tractor propeller—See PROPELLER, TRACTOR.

trailing edge—The rearmost edge of an airfoil or propeller blade. (Fig. 1.)

trail rope—See ROPE, DRAG.

trajectory band—See BAND, TRAJECTORY.

transverse, intermediate—An open unbraced transverse frame of a rigid airship which lies between two main or braced transverse frames. (Fig. 4.)

transverse, main—A main transverse strengthening frame of a rigid airship provided with wire or girder bracing and spaced at regular intervals throughout the length of the airship. (Fig. 4.)

trapeze bar—See BAR, SUSPENSION.

triangulation balloon—See BALLOON, TRIANGULATION.

trim—The attitude of an aerostat relative to a fore-and-aft horizontal plane. If the forward end is down, the aerostat is said to have "trim by the bow"; if the after end, it has "trim by the stern."

trim, to—To alter the attitude of an aerostat relative to a fore-and-aft horizontal plane. If the endeavor is to force the bow down, the aircraft is "trimmed by the bow"; if the stern, it is "trimmed by the stern." If the aircraft shows a tendency to sink by the bow end, it is said to "trim by the bow" or to be "bow-heavy"; if the tendency is to sink by the stern, it is said to "trim by the stern" or to be "stern-heavy."

trim, dynamic—Trim (or trimming) due to dynamic conditions or their change.

trim, static—Trim (or trimming) due to static conditions or their change.

triplane—An airplane with three main supporting surfaces, placed one above another.

trolley, docking—A car or trolley fitted on (or in) docking rails to transmit the pull of an airship docking line. It is fitted with wheels having antifriction bearings so it can move freely in the rail. Usually some sort of quick-release device for letting go the line is also fitted.

tube, inflation—A fabric tube leading from the inflation manifold or source of supply to the inflation sleeve of the gas cell or envelope.

tube, nursing—See TUBE, SUPPLY.

tube, pressure—A tube fitted to an envelope or gas bag, to which a pressure gauge may be attached.

tube, supply—An elongated appendix or inflation sleeve, fitted on a kite balloon, which is brought down to the basket and fitted with a quick-connection coupling. This coupling can be attached to a similar piece on the deck of the airship and gas may be sent into the balloon shortly after it has reached the deck. A similar tube is sometimes used with airships where constant-pressure nurse balloons are used. This is rare in the United States. (Fig. 2.) Also called "nursing tube."

turn indicator—See INDICATOR, TURN.

turn, reverse—A rapid maneuver to reverse the direction of flight of an airplane, made by a half loop and half roll.

unstable oscillation—See OSCILLATION, UNSTABLE.

useful lift—See LIFT, USEFUL (AIRSHIP).

useful load—See LOAD, USEFUL.

valve, automatic—A spring-loaded relief valve fitted to the envelope, ballonet, or gas cell of an aerostat and set to open at a predetermined pressure for the purpose of preventing excessive internal pressure. (Figs. 4 and 5.)

Also applied to a type of valve used on some aerostats which opens at a predetermined contained volume or hull dimension.

valve cover—See HOOD, VALVE.

valve hood—See HOOD, VALVE.

valve, maneuvering—A manually operated valve fitted to the envelope, ballonet, or gas cell of an aerostat for the purpose of releasing gas or air from within the envelope or gas cell when desired. (Fig. 4.)

valve petticoat—A special sleeve between valve and gas container making it possible to tie off the sleeve and change valves without loss of gas.

valve seal—A fabric cover used to seal the automatic valves of a rigid airship when docked in the shed. Jam pot cover (British).

veneer—Thin sheets of wood, either sliced with a knife or sawed.

vent, pressure-relief—A small opening in the covering of the fin of an airship intended to facilitate the equalization of the pressure of the air within the fin with that of the outside air. It also provides an outlet for any gas that may collect in the fin.

Venturi, power—A Venturi tube used to operate gyroscopic turn indicators and other instruments.

Venturi, speed-indicating—A Venturi tube may be combined with a Pitot tube or with a tube giving static pressure to form a pressure nozzle which may be used to determine the indicated speed of an aircraft through the air. The pressure difference is measured by a suitable gauge.

Venturi tube—A short tube with flaring ends and a narrow or constricted section between them, into which a side tube opens. When fluid flows through the Venturi, there is a reduction of pressure in the constricted section, the amount of the reduction being a function of the velocity of flow. (Fig. 8.)

vertical engine—See ENGINE, VERTICAL.

vertimeter—A device for indicating the rate of rise and fall of an aerostat, usually a special form of statoscope. A rate-of-climb meter serves the same purpose, although of a different form.

volume—The volume of the air displaced by the gas used for inflation.

volume, aerodynamic (**airship**)—The volume of the form which must be driven through the air. Same as "air volume."

volume, air (**airship**)—The volume of air displaced by the body formed by the outer cover or envelope of an airship. It is this volume which enters into aerodynamic computations. See VOLUME, AERODYNAMIC (AIRSHIP).

volume, gas (**airship**)—The volume of the contained gas. See CAPACITY.

V-type engine—See ENGINE, V-TYPE.

V-wires—The lower lines of the winch suspension of the kite balloon. They meet at the junction piece and form V's; hence the name. (Fig. 2.)

walkway girder—See GIRDER, WALKWAY.

warp—To change the form of a wing by twisting it. Warping is sometimes used to maintain the lateral equilibrium of an airplane.

wash—The disturbance in the air produced by the passage of an airfoil. Also called the "wake" in the general case for any solid body.

washin—Permanent warping of the wing which results in an increase in the angle of attack near the tip.

washout—Permanent warping of a wing which results in a decrease in the angle of attack near the tip.

water-recovery apparatus—See APPARATUS, WATER-RECOVERY.

water-recovery condenser—See CONDENSER, WATER-RECOVERY.

weight, dischargeable (**consumable weight**) (**airship**)—All weight which can be consumed or discharged and still leave the airship in safe operating condition with a specified reserve of fuel, oil, water ballast, and provisions, and her normal crew.

weight, disposable (**airship**)—All weight other than fixed weights, including dischargeable weights contrasted with fixed weights, q. v.

weight, empty—The structure, power plant, and fixed equipment of an aircraft. Included in this fixed equipment are the water in the radiator and cooling system, all essential instruments and furnishings, fixed electric wiring for lighting, heating, etc. In the case of the aerostat the amount of ballast which must be carried to assist in making a safe landing must also be included.

weight, fixed (**airship**)—The weight of the hull machinery and all equipment and parts which are fixed in position and nonconsumable. All constant and nonconsumable weights which an airship would carry under all conditions of service (British). Liquids in cooling systems of engines are included.

weight, fixed power-plant, for a given airplane—The weight of an engine, including ignition, carburetor, and induction systems complete, propeller and hub, exhaust manifolds, radiator and water, *if used*, with all interconnecting wires, controls, tanks, and pipes, lubricating-oil temperature regulators, *the oil contained in the engine crankcase* and the starting gear attached to the engine, but excluding fuel, oil, and engine instruments.

weight per horsepower—The dry weight of an engine divided by the rated horsepower.

winch, suspension—See SUSPENSION WINCH.

windmill—An air-driven screw used to drive auxiliary apparatus on an aircraft.

window, inspection—A small transparent window fitted in the envelope of a balloon or airship, or in the wing of an airplane, to allow inspection of the interior. (Figs. 1 and 3.)

wind, relative—The motion of the air with reference to a body, i. e., its motions as observed by a man at rest on the body. The direction and velocity of the relative wind, therefore, are found by adding two vectors, one being the velocity of the air with reference to the earth, the other being equal and opposite to the velocity of the body with reference to the earth.

wind tunnel—An elongated chamber, usually a tube divergent at the ends, through which a steady air stream may be drawn or forced. Models of airfoils, of aircraft, or of propellers may be placed in the middle portion of the tunnel, called the experiment chamber or working section, and supported by suitable balances placed outside the air stream, so that the forces, moments, etc., due to the moving air may be measured.

wing—A general term applied to a whole or a portion of the main supporting surfaces of an airplane, but in the latter case is usually qualified as right wing, left wing, upper wing, or lower wing, etc.

wing car—See CAR, WING.

wing-dihedral angle—See ANGLE, WING-DIHEDRAL or DIHEDRAL.

wing drag—See DRAG.

wing-heavy—The condition of an airplane in which (in normal flight) there is a tendency for the right (or left) wing to drop, if the lateral control is released, i. e., the condition in which the pilot has to exert a lateral force on the control stick to keep the lateral axis horizontal.

wing loading—See LOADING, WING.

wing rib—A fore-and-aft member of the wing structure of an airplane, used to give the wing section its form and to transmit the load from the fabric to the spars. (Figs. 1 and 15.)

rib compression—A heavy rib designed to have the function of a wing rib and also to act as a strut opposing the pull of the wires in the internal drag-truss. (Also called "Drag strut.") (Figs. 1 and 15.)

rib, former or false—An incomplete rib, frequently consisting only of a strip of wood extending from the leading edge to the front spar, which is used to assist in maintaining the form of the wing where the curvature of the airfoil section is sharpest. (Figs. 1 and 15.)

wing setting, angle of—See ANGLE OF WING SETTING.

wing skid—See SKID.

wing spar—The principal transverse structural member of the wing assembly of an airplane. (Figs. 1 and 15.)

wing truss—The framing by which the wing loads of an airplane are transmitted to the fuselage. It comprises struts, wires, cables, tie rods, and spars.

wire—In aeronautics, refers specifically to drawn solid wire.

wire (airship):

antiflutter—A wire in the plane of the outer cover for locally reinforcing the outer cover in that part of the airship and reducing fluttering in flight due to air pressure or propeller wash. Also called "outer cover support wire."

chord—A wire joining the vertices of the polygonal frame of the main transverse frame. (Fig. 4.)

diametral—A chord wire which passes through or near the center of the main transverse frame. It is usually attached to the axial fitting. (Fig. 4.)

fairing—A wire provided as a point of attachment for the outer cover to maintain the contour lines of the envelope of an airship.

main shear—A diagonal wire taking up mean shear loads in the structure of a rigid airship.

netting—Diagonal and/or circumferential wire netting fitted between the longitudinals over the entire hull of a rigid airship, to transmit the lift of the gas cells to the structure. Sometimes called "gas pressure wires." (Fig. 4.)

radial—A wire which extends from an axial fitting at the center of the transverse frame of a rigid airship to a joint of the frame.

secondary shear—Additional reinforcing shear wire.

wire, antidrag—A wire designed primarily to resist forces acting parallel to the chord of the wing of an airplane and in the same direction as the direction of flight. It is generally inclosed in the wing. (Fig. 1.)

wire, drag—Any wire or cable designed primarily to resist drag forces.

internal—A drag wire concealed inside the wing. (Fig. 1.)

external—A drag wire run from a wing to the fuselage or other part of the airplane. (Fig. 1.)

wire, landing—A wire designed primarily to resist forces in the opposite direction to the normal direction of the lift and to oppose the lift wire and prevent distortion of the structure by an overtightening of those members. (Fig 1.) Sometimes called "antilift" wire.

wire, lift—A wire or cable which transmits the lift on the outer portion of the wing of an airplane in toward the fuselage or nacelle. This wire usually runs from the top of an interplane strut to the bottom of the strut next nearer the fuselage. Sometimes called "flying wire." (Fig. 1.)

wire, stagger—A wire connecting the upper and lower surfaces of an airplane and lying in a plane substantially parallel to the plane of symmetry. (Also called "incidence wire.") (Fig. 1.)

wood, laminated—A product formed by gluing or otherwise fastening together a number of laminations of wood with the grain substantially parallel. (Differs from plywood in that in the latter the grain of alternate plies is usually crossed at right angles; also, the plies of the latter are usually made up of veneer.)

W-type engine—See ENGINE, W-TYPE.

yaw, angle of—See ANGLE OF YAW.

yaw guy—See LINE, YAW.

yaw line—See LINE, YAW.

yawmeter—An instrument for measuring the angle of yaw.

zero-lift angle—See ANGLE, ZERO-LIFT.

zero-lift line—A line through the trailing edge of an airfoil section parallel to the direction of the wind when the lift is zero.

zoom—To climb for a short time at an angle greater than that which can be maintained in steady flight, the airplane being carried upward at the expense of its kinetic energy. This term is sometimes used as a noun, to denote any sudden increase in the upward slope of the flight path.

REPORT No. 240

NOMENCLATURE FOR AERONAUTICS

By The National Advisory Committee for Aeronautics

PART II

NOMENCLATURE BY DIVISIONS

A. GENERAL TERMS

aerodynamics—The branch of dynamics which treats of the motion of air and other gaseous fluids and of the forces acting on solids in motion relative to such fluids.

aeronautics—The science and art pertaining to the flight of aircraft.

aerostatics—The science that treats of the equilibrium of gaseous fluids and of solid bodies immersed in them.

As an aeronautic term, it relates to those properties of lighter-than-air craft which are due to the buoyancy of the air.

aerostation—The art of operating aerostats.

aircraft—Any weight-carrying device or structure designed to be supported by the air, either by buoyancy or by dynamic action.

airport—A locality, either of water or land, which is adapted for the landing and taking off of aircraft and which provides facilities for shelter, supply, and repair of aircraft; or a place used regularly for receiving or discharging passengers or cargo by air.

airway—An air route between air traffic centers which is over terrain best suited for emergency landings, with landing fields at regular intervals equipped with aids to air navigation and a communication system for the transmission of information pertinent to the operation of aircraft.

The term "airway" may apply to an air route for either landplanes or seaplanes or both.

aviation—The art of operating heavier-than-air craft.

cross-country flight—A flight which necessitates leaving the vicinity of a regular landing field.

pilot—An operator of aircraft. This term is applied regardless of the sex of the operator.

B. TYPES OF AIRCRAFT

aerostat—A generic term for aircraft whose support is chiefly due to buoyancy derived from aerostatic forces. The immersed body consists of one or more bags, cells, or other containers, which are filled with a gas which is lighter than air.

Syn.—LIGHTER-THAN-AIR CRAFT. Includes airship and balloon, q. v.

airplane—A mechanically driven aircraft, heavier than air, fitted with fixed wings, and supported by the dynamic action of the air. (Figs. 1, 6, 9, 10, and 14.)

glider—A form of aircraft similar to an airplane, but without a power plant.

helicopter—A form of aircraft whose sole support in the air is derived directly from the vertical component of the thrust produced by rotating airfoils.

kite—An aircraft heavier than air, restrained by a towline and sustained by the relative wind.

ornithopter—A form of aircraft heavier than air, deriving its chief support and propelling force from flapping wings.

C. TYPES OF AEROSTATS

airship—An aerostat provided with a propelling system and with means of controlling the direction of motion. When its power plant is not operating, it acts like a free balloon.

- **nonrigid**—An airship whose form is maintained by the internal pressure in the gas bags and ballonets. (Fig. 3.)
- **rigid**—An airship whose form is maintained by a rigid structure. (Fig. 4.)
- **semirigid**—An airship whose form is maintained by means of a rigid or jointed keel in conjunction with the internal pressure in the gas containers and ballonets. (Fig. 5.)

  The term ''airship'' is sometimes incorrectly applied to heavier-than-air craft either in full or as ''ship.'' This is a slang use of the word and should be avoided.

balloon—An aerostat without a propelling system.

- **barrage**—A small captive balloon used to support wires or nets which are intended as a protection against attacks by aircraft.
- **captive**—A balloon restrained from free flight by means of a cable attaching it to the earth.
- **constant pressure***—A supply balloon arranged to maintain a constant pressure of gas in a moored or docked aerostat.
- **free**—A balloon, usually spherical, whose ascent and descent may be controlled by use of ballast or with a loss of the contained gas and whose direction of flight is determined by the wind. (Fig. 11.)
- **kite**—An elongated form of captive balloon fitted with lobes to keep it headed into the wind and usually deriving increased lift due to its axis being inclined to the wind. (Fig. 2.)
- **nurse***—Sometimes used to refer to a constant-pressure balloon.
- **observation**—A captive balloon used to provide an elevated observation post.
- **pilot***—A small balloon sent up to show the direction and speed of the wind.
- **propaganda**—A small free balloon sent up without passengers but with a device by which papers or documents may be dropped at intervals.
- **sounding***—A small balloon sent up without passengers but with recording meterological instruments.
- **supply***—A container made of heavy fabric employed as a portable means of storing gas at low pressure. It is usually too heavy to rise even if free.
- **triangulation**—A small captive balloon used as a mark on which to sight in a triangulation survey.

D. TERMS RELATING TO AEROSTATS

(*a*) OPERATION

ballast—Any substance, usually sand or water, carried in a balloon or airship and intended to be thrown out, if necessary, for the purpose of reducing the load carried and thus altering the aerostatic relations. (Figs. 4 and 5.)

bow-heavy—The condition of an airship which, when at rest in still air, trims with its axis inclined down by the bow. The term "bow-heavy" is preferred to "nose-heavy" in describing airships.

breathing—The passage of air into or out of an aerostat, due to the changing of its volume.

breathing stresses—Stresses produced in an aerostat by breathing. Of importance in the envelope and keel of a semirigid airship due to the interaction of envelope and keel when the envelope "breathes."

danger cone—A pennant on the wire cable of a captive balloon to warn aircraft of its presence. Usually a hollow cone of light cloth.

deflation—The act of removing gas and air from an aerostat.

deflation sleeve—Generally a sleeve or appendix made of fabric provided for the special purpose of facilitating the deflation of an aerostat. Also applied to the sleeve or appendix fitted in the lower lobe of a kite balloon and used to permit the rapid escape of air in the lobes when the balloon is hauled down. (Fig. 2.)

---

*Those forms of balloons marked with an asterisk (*) are not, strictly speaking, aircraft.

D. TERMS RELATING TO AEROSTATS—Continued

(*a*) Operation—Continued

gassing—The operation of replenishing a balloon with fresh gas to increase the purity or to make up for a loss of gas.

gassing factor.—The quantity of aerostatic gas required to maintain an aerostat for one year. It is ordinarily expressed as a percentage of the gas volume.

hog—A distortion of an airship in which the longitudinal axis becomes convex upward so that both ends droop.

inflation—The act of filling a balloon or airship with gas.

sag—A distortion of an airship in which the longitudinal axis becomes concave upward so that both ends rise.

stern-droop—A deformation of an airship in which its longitudinal axis bends downward at the after end.

stern-heavy—The condition in which, in normal flight, the after end of an airship tends to sink and which requires correction by means of the horizontal controls. In this condition an airship is said to "trim by the stern." It may be due to either aerodynamic or static conditions or to both.

superheat—The amount by which the temperature of the gas in the envelope or gas cells of an aerostat is higher than the temperature of the surrounding air. If the contained gas has a lower temperature, the superheat is said to be negative.

trim—The attitude of an aerostat relative to a fore-and-aft horizontal plane. If the forward end is down, the aerostat is said to have "trim by the bow;" if the after end, it has "trim by the stern."

trim, to—To alter the attitude of an aerostat relative to fore-and-aft horizontal plane. If the endeavor is to force the bow down, the aircraft is "trimmed by the bow;" if the stern, it is "trimmed by the stern." If the aircraft shows a tendency to sink by the bow end, it is said to "trim by the bow" or to be "bow-heavy;" if the tendency is to sink by the stern, it is said to "trim by the stern" or to be "stern-heavy."

(*b*) Principal Parts

ballonet—A compartment of variable volume constructed of fabric, or partitioned off, within the interior of a balloon or airship. It is usually partially inflated with air, under the control of valves, from a blower or from an air scoop. By the blowing in or letting out of air, it serves to compensate for changes of volume in the gas contained in the envelope and to maintain the gas pressure, thus preventing deformation or structural failure. By means of two or more ballonets, often used in nonrigid airships, the trim can also be controlled. The ballonet should not be confused with gas cell. (Figs. 2, 3, and 5.)

ballonet diaphragm—The fabric partition between the gas and air compartments of the envelope of a nonrigid or semirigid airship or kite balloon.

basket—The structure suspended beneath a balloon for carrying passengers, ballast, etc. (Figs. 2 and 11.) It is usually used on a free or kite balloon.

bow-cap—(1) A cap of metal or fabric used to reinforce the extreme forward ends of the bow stiffeners of a nonrigid or semirigid airship. (Figs. 3 and 5.)

(2) The conical or cap-shaped structure at the extreme bow of a rigid airship to which the longitudinal girders are attached and which supports the bow mooring spindle. (Fig. 4.)

bow-stiffener—A rigid member attached to the bow of a nonrigid or semirigid envelope to reinforce it against the pressure caused by the motion of the airship. Sometimes called "nose stiffener" or "nose batten." (Figs. 3 and 5.)

car—That portion of an airship which is intended to carry power unit or units, personnel, cargo or equipment. It may be suspended from the buoyant portion or it may be built close up against it. It is not to be applied to parts of the keel of a rigid or semirigid airship which have been fitted for the purposes mentioned. (Figs. 3, 4, 5, 12, and 13.)

D. TERMS RELATING TO AEROSTATS—Continued

(*b*) PRINCIPAL PARTS—Continued

control car—The car of an airship in which controls are centralized and from which it is operated. (Figs. 3, 4, 5, 12, and 13.)

control compartment—A compartment in the control car of an airship from which all controls are operated. It may be compared to the pilot house of a ship.

envelope—The outer covering of an aerostat, usually of fabric. It may or may not be also the gas container. It may be divided by diaphragms into separate gas compartments or cells, and it may also contain internal air cells or ballonets. (Figs 2, 3, 4, 5, 11, 12, and 13.)

gas cell—One of the gas-containing units fitted in a rigid airship. Sometimes called "gas bag." (Fig. 4.)

gore—The portion of the envelope of a balloon or airship included between two adjacent meridian seams.

hull—The main structure of a rigid airship, consisting of a covered elongated framework which incloses the gas cells and supports the cars and equipment. (Fig. 4.) May also be applied to the complete buoyant unit of any aerostat. In this latter sense sometimes called "gas bag."

intermediate longitudinal—An intermediate longitudinal strength member, of a rigid airship, which lies between two adjacent main longitudinals and is generally of lighter weight and/or smaller dimensions than the main longitudinals. (Fig. 4.)

intermediate transverse—An open unbraced transverse frame of a rigid airship which lies between two main or braced transverse frames. (Fig. 4.)

keel—The assembly of members at the bottom of the hull of a semirigid or rigid airship which provides special strength to resist hogging and sagging and also serves to distribute the effect of concentrated loads along the hull. It may be a simple Gall's chain, as in some semirigids, or a very extensive structure inclosing the corridor, as in most rigids. (Figs. 4 and 5.)

lobe—An air or gas inflated bag fitted at the stern of a kite balloon and acting as a fin or stabilizer to give it aerodynamic stability. (Fig. 2.)

main longitudinal—A main longitudinal strength member, of a rigid airship, which connects the various transverse frames. (Fig. 4.)

main transverse—A main transverse strengthening frame of a rigid airship provided with wire or girder bracing and spaced at regular intervals throughout the length of the airship. (Fig. 4.)

observation platform—A platform or small deck fitted on the top of an airship and used as a post for a lookout and defense, or as a place from which to make observations used in navigating the airship. (Figs. 4 and 5.)

outer cover—The outside covering of a hull of a rigid airship, usually of some kind of fabric. Sometimes called the "envelope." (Figs. 4 and 5.)

sighting pendant—A vertical wire on center line and forward of the control car of an airship, used as a mark in steering, to assist in determining wind direction.

stern framing—All framework, aft of the cruciform girder, necessary to complete the shape and contour of a rigid airship.

wing car—A car suspended off the center line of an airship. It is also called "side car." (Fig. 4.)

wire:

- **antiflutter**—A wire in the plane of the outer cover for locally reinforcing the outer cover in that part of the airship and reducing fluttering in flight due to air pressure or propeller wash. Also called "outer cover support wires."
- **chord**—A wire joining the vertices of the polygonal frame of the main transverse frame. (Fig. 4.)
- **diametral**—A chord wire which passes through or near the center of the main transverse frame. It is usually attached to the axial fitting. (Fig. 4.)

D. TERMS RELATING TO AEROSTATS—Continued

(*b*) Principal Parts—Continued

wire—continued.

  fairing—A wire provided as a point of attachment for the outer cover to maintain the contour lines of the envelope of an airship.

  main shear—A diagonal wire taking up main shear loads in the structure of a rigid airship.

  netting—Diagonal and/or circumferential wire netting fitted between the longitudinals over the entire hull of a rigid airship to transmit the lift of the gas cells to the structure. Sometimes called "gas pressure wires." (Fig. 4.)

  radial—A wire which extends from an axial fitting at the center of the transverse frame of a rigid airship to a joint of the frame.

  secondary shear—Additional reinforcing shear wire.

(*c*) Detailed Parts and Fittings

air duct—A tube, usually of fabric, supplying air for filling or for maintaining pressure in air-filled parts of an aerostat.

(a) The duct joining the vertical and lateral lobes of a kite balloon. Sometimes called "interconnecting sleeve" or "trousers" (British). (Fig. 2.)

(b) The duct leading from the air scoop or blower of a nonrigid or semirigid airship to the ballonet or ballonets. (Figs. 2 and 5.)

air scoop—A projecting scoop which uses the wind or slip stream to maintain air pressure in the interior of the ballonet of an aerostat. (Figs. 2, 3, and 12.)

A similar device is sometimes used on airplanes to produce ventilation. (Fig. 4.)

appendix—The tube, usually located at the bottom of a balloon, primarily used for inflation and deflation. In the case of a free balloon it may also serve as an automatic discharge opening. (Fig. 11.)

Originally applied to free balloons only. Should be restricted to the various types of balloons and not applied to airships.

appendix manhole—An appendix of large diameter and usually rather short. It is used more for access than for inflation or deflation. (Fig. 2.)

automatic valve—A spring-loaded relief valve fitted to the envelope, ballonet, or gas cell of an aerostat and set to open at a predetermined pressure for the purpose of preventing excessive internal pressure. (Figs. 4 and 5.)

Also applied to a type of valve used on some aerostats which opens at a predetermined contained volume or hull dimension.

axial cable—The axial member (usually steel wire cable) sometimes fitted in a rigid airship. It is attached to the central fitting of the radial or diametral wires of each main transverse and to the hull structure at bow and stern. Its purpose is to provide support for the radial or diametral wires in an axial direction and thus assist them to sustain the load which might be caused by unequal pressure in adjacent cells or by the airship being pitched to a large angle. (Fig. 4.)

axial cone—The cone-shaped fabric fitting in the end of a gas cell of a rigid airship, which provides a gas-tight connection of the cell to the axial cable and yet permits the cell some degree of freedom in its movements. A special form of conical sleeve. (Fig. 4.)

band:

  mooring—A band of tape or webbing over the top of a kite balloon to which the mooring ropes are attached. It forms part of a mooring harness. (Fig. 2.)

  suspension—A horizontal fabric band securely fastened to the envelope of a balloon or airship and to which are attached the main suspensions of the basket or car, or the captive cable of a kite balloon. (Fig. 2.)

  trajectory—A band of webbing carried in a special curve over the surface of the envelope of an airship to distribute the stresses due to the suspension of the car. (Fig. 13.)

D. TERMS RELATING TO AEROSTATS—Continued

(c) DETAILED PARTS AND FITTINGS—Continued

batonet—A special form of toggle, usually quite slender and truly cylindrical except for the groove, and used to attach the rigging of a balloon or airship to a fabric loop or suspension band on the envelope.

box girder—Any girder of rectangular section. Frequently used to refer to the rectangular, longitudinal members in the keel of a rigid airship from which fuel tanks and gas bags are suspended.

bridle—A sling of cordage or wire which has its ends fixed at two different points, to the bight of which a single line may be attached, either movably or fixed, thus distributing the pull of the single line to two points or more in the case of a multiple bridle. This term is also used to refer to a towing or mooring line having two legs and intended to reduce yawing when towing or mooring.

bullseye—A circular thimble.

catenary—A line or length of cordage which is secured to or in a piece of fabric in the form of a catenary curve or a series of such curves. (Fig. 5.)

chafing patch—A patch of fabric secured to the envelope of an aerostat to protect it from abrasion.

channel patch—A channel-shaped fabric-fitting secured to the envelope of an aerostat to allow a rod or spar to be laced to the envelope.

climbing shaft—An access shaft fitted with a ladder and leading from the bottom to the top of an airship hull. This may be fitted to an airship of any type. (Figs. 4 and 5.)

concentration ring:

- **airship**—A ring to which several rigging lines are led from the envelope and from which one or more lines also lead to the car.
- **free balloon**—A ring to which are attached the ropes suspending the basket and to which the net is also secured. Sometimes called "load ring." (Fig. 11.)

conical sleeve—A cone-shaped fabric, fitting in a bag or cell through which a line passes. It provides a gas-tight connection of the bag or cell to the line and yet permits both some degree of freedom to move.

control lines—Lines of wire and/or stranded cable leading from the control car or compartment to the various parts of an airship, and operating either through mechanisms or directly, the rudders, valves, etc., which control the speed, altitude, etc., of the airship.

cradle:

- **building**—A support provided for the frame of a rigid airship or the keel of a semirigid airship during construction.
- **docking**—A support for the car of an airship while it is being inflated in the shed. Mostly used with rigid airships.

crow's-foot—A system of diverging short ropes for distributing the pull of a single rope.

An arrangement in which the strands of a cord are opened out so that they can be effectively cemented to a fabric surface.

cruciform girder—The structure, consisting of vertical and horizontal transverse girders, which is fitted at the stern of a rigid airship for the purpose of supporting the inboard ends of the sternposts of the fins or the rudderposts. It may be integral with the sternposts which form the after ends of the fins.

drag rope—A long rope which can be hung overboard from a balloon so as to act as a brake and a variable ballast in making a landing. Same as "trail rope" or "guide rope." On airships a similar rope, or ropes, is used as a haul-down or mooring line by the landing crew. It is usually larger and longer than the regular handling lines. Sometimes called "grab line."

drip flap—A strip of fabric attached by one edge to the envelope of an aerostat so that rain runs off its free edge instead of dripping into the basket or car. It also assists in keeping the suspension ropes dry and nonconducting. Also called "drip band" and "drip strip."

D. TERMS RELATING TO AEROSTATS—Continued

(c) DETAILED PARTS AND FITTINGS—Continued

D-ring—A ring having (as the name implies) the shape of a capital D, to which rope suspensions are attached.

field-handling frame—A portable frame which may be attached to an airship when it is on the ground and which is intended to afford a grasp to more men than could get on the handling rails of the cars. These frames are rarely carried when in flight. (Fig. 4.)

finger patch—A special form of patch having extensions or "fingers" extending out from the central portion. The "fingers" may be of tape, frayed-out rope, or fabric. Their function is to distribute the load more widely to the fabric of the envelope or gas cells. (Fig. 12.)

fin carrier—A frame to which the inboard edge of the fin of a nonrigid or semirigid airship is attached, so as to prevent the edge of the fin from sinking into the envelope.

fin girder—A girder of a rigid airship which goes to make up the fin.

gas shaft—A duct or shaft leading from the bottom of the gas cells to the outer cover of an airship. It affords a clear passage for the escape of gases which have accumulated in the gangway or corridor, or which are discharged from the valves at the bottom of the cells. It usually consists of light wooden hoops or frames spaced at intervals on cords or wires, and is covered by a netting. It prevents the gas cells from closing hard against one another and thus keeps the passage open. Sometimes called "gas trunk," "exhaust-gas shaft," or "trunk."

In view of the possibility of confusion with parts of an engine-exhaust system, it is believed that "gas shaft" or "trunk" is to be preferred. (Fig. 4.)

gas-shaft hood—A hood or cowl, located on the outer cover of a rigid airship at the outer end of a gas shaft. It is usually made of light wood and fabric and is faced to facilitate the escape of gas. Sometimes called "exhaust-gas hood."

In view of the possibility of confusion with the parts of an engine exhaust system, it is believed that "gas-shaft hood" is to be preferred. (Fig. 4.)

gland—A short tube fitted to an envelope or gas bag in such a manner that a rope or line may slide through without leakage of gas or air. (Figs. 2 and 5.)

grommet—A small ring of chord.

handling line—A line attached along the side of an airship for use in maneuvering near and on the ground. (Figs. 2, 3, 4, and 5.) Sometimes called "grab line."

inflation manifold—A metal or fabric connection with numerous inlets which permit the passage of gas at the same time from a number of sources (either cylinders or gas holders) to the main inflation tube.

inflation sleeve (or filling sleeve)—A tubular fabric attachment to an envelope or gas bag, serving as a lead for the inflation tube. (Figs. 3 and 5.)

inflation tube—A fabric tube leading from the inflation manifold or source of supply to the inflation sleeve of the gas cell or envelope.

jackstay—A longitudinal rigging provided to maintain the correct distance between various parts or fittings on an aerostat.

main mooring line—The line dropped from the bow of an airship to be coupled to the mast main mooring line. (Fig. 4.)

maneuvering valve—A manually operated valve fitted to the envelope, ballonet, or gas cell of an aerostat for the purpose of releasing gas or air from within the envelope or gas cell when desired. (Fig. 4.)

maneuvering-valve hood—A hood, or cowl, located on the outer cover of a rigid airship just over a maneuvering valve. It is usually made of light wood or fabric and is faced to facilitate the escape of gas. (Fig. 4.)

manometer-tube gland—A gland fitted to the envelope of an aerostat to form a gas-tight connection for the tube leading to the manometer in the car. Same as "pressure-tube gland."

D. TERMS RELATING TO AEROSTATS—Continued

(c) DETAILED PARTS AND FITTINGS—Continued

mooring cone—The grooved conical member at the extreme bow of an airship which engages with a hollow cone at the top of the mooring mast and provides the coupling between the airship and the mooring mast. (Fig. 4.)

mooring-cone outrigger—The member, usually tubular, which supports the mooring cone at the bow of the airship. Sometimes referred to as "mooring spindle." (Fig. 4.)

mooring harness—A system of webbing bands, fitted over the top of the envelope of a balloon, to which are attached the mooring ropes. Usually found only in kite balloons or observation balloons. (Fig. 2.)

mooring line—A line attached near the bow of an airship for securing it to the ground or to a mooring mast. (Figs. 3, 4, and 5.)

mooring ring—A metallic ring suspended from one of the forward frames of a rigid airship by wire lines and used for mooring. The vertex of a "three-point mooring" is attached to this ring.

mooring rope—A line attached to a balloon or airship for use in securing it to the ground. It may serve the purpose of a "handling line," or vice versa. (Fig. 2.)

net:

- **free-balloon**—A rigging made of ropes and twine shaped to the upper surface of the envelope, which supports the weight of the basket, etc., and distributes the load over the entire upper surface of the envelope. (Fig. 11.)
- **gas-cell (rigid airship)**—A netting of cord of small mesh which is intended to assist the fabric of the gas cells in transmitting gas force to a wire netting of coarser mesh and to the longitudinals, both being fitted between the longitudinals. It may be compared to the net of a free balloon. Sometimes called "gas-cell netting" or "cord netting." (Fig. 4.)
- **inflation**—A rectangular net of cordage used to restrain the envelope of the kite balloon or airship during inflation. Also applied to a free-balloon net designed to be removed after inflation.

patch—A strengthened or reinforced flap of fabric of special shape and construction, which is cemented to the envelope or gas cell. It usually forms an anchor by which some portion of the structure may be attached to the envelope or to which the positioning lines, controlling the gas cell, may be attached to the cell. (Fig. 12.)

pressure flap—A flap valve fitted in the outer cover or envelope of a rigid airship and arranged to permit the rapid flow of air in and out, particularly inward. The purpose is to facilitate the rapid equalization of the pressure of the air within the envelope with that of the surrounding air.

pressure-relief vent—A small opening in the covering of the fin of an airship intended to facilitate the equalization of the pressure of the air within the fin with that of the outside air. It also provides an outlet for any gas that may collect in the fin.

pressure tube—A tube fitted to an envelope of a gas bag, to which a pressure gauge may be attached.

propeller reinforcing girder—A light additional member fitted in the structure of a rigid airship to reinforce those areas of the outer cover which are affected by the propeller wash.

quadrant—The operating lever, made on the arc of a circle of a control surface of an airship, e. g., rudder quadrant, elevator quadrant. (Fig. 4.)

rip cord—The rope running from the rip panel to the car or basket, the pulling of which tears off or rips the rip panel and causes immediate deflation. (Figs. 2 and 3.)

rip panel—A strip of fabric inserted or fitted in the upper part of the envelope of a balloon or semirigid or nonrigid airship which is torn or ripped open when immediate deflation is desired. (Figs. 2 and 3.)

D. TERMS RELATING TO AEROSTATS—Continued

(*c*) Detailed Parts and Fittings—Continued

rudder (airship)—A hinged or pivoted surface, usually attached to a fin at the after end of an airship. When operated by the pilot it produces a yawing moment and gives directional control in the plane at right angles to the axis about which it is hinged or pivoted. (Figs. 3, 4, and 5.)

safety loop—A loop formed in a rip cord and attached to a securing patch by a breakable cord or a spring clip. It may be formed either inside the envelope and close to the rip panel, or outside the envelope near the gland by which the rip cord passes through the envelope. Before the rip panel can be "pulled" the breakable cord must be broken or the clip opened. Accidental "pulling" is thus made unlikely, as the weight of the cord is easily carried by the breakable cord or spring clip.

sandbag line—A rope extending along the line of suspension ropes or bridles of a kite balloon to which are hooked the sandbags used in mooring the balloon. The purpose is to prevent wear on the suspension cordage.

sandbag loop—A system of cordage loops on the envelope of a balloon for suspending sandbags. See also SANDBAG LINE.

sea anchor—An open fabric bag carried on an aircraft and arranged to offer considerable resistance when towed mouth first through the water. Tripping or collapsing devices may be incorporated in it. Also called "drogue."

supply tube—An elongated appendix or inflation sleeve, fitted on a kite balloon, which is brought down to the basket and fitted with a quick-connection coupling. This coupling can be attached to a similar piece on the deck of the airship and gas may be sent into the balloon shortly after it has reached the deck. A similar tube is sometimes used with airships where constant pressure nurse balloons are used. This is rare in the United States. (Fig. 2.) Also called "nursing tube."

suspension bar—A bar to which the supporting ropes of the basket of a balloon are secured. It is also fitted with ropes and toggles for attaching to the basket suspensions from the balloon. Also called "trapeze bar." (Figs. 2 and 11.)

suspension line—A line either of cordage or metal which supports the weight attached to the envelope of a balloon or airship. (Figs. 2, 3, 4, 5, and 11.)

suspension patch—A patch, secured to the envelope or to a gas cell of an aerostat, to which a suspension line may be attached. (Fig. 12.)

thimble—A grooved ring of circular, pear-, or heart-shaped form, generally of metal, which is inserted in the eye of a rope or wire to prevent chafing or deformation of the eye.

toggle—A short crossbar of wood or metal which is fitted at the end of a rope. The rope passes around the mid-length of the bar in a shouldered groove. By slipping it through an eye in the end of another rope, the two lengths of rope can be quickly connected or disconnected. (Fig. 2.)

topping up—The operation of filling up with gas an already partially full aerostat. Also applied to a similar operation with *fuel tanks*. *Incorrectly* called "nursing."

valve hood—The appliance, having the form of a hood or parasol which protects the valve of an airship or balloon against rain. Also called "valve cover" or "bonnet." (Figs. 2 4, and 5.)

valve petticoat—A special sleeve between valve and gas container making it possible to tie off the sleeve and change valves without loss of gas.

valve seal—A fabric cover used to seal the automatic valves of a rigid airship when docked in the shed. Jam pot cover (British).

V-wires—The lower lines of the winch suspension of the kite balloon. They meet at the junction piece and form V's; hence the name. (Fig. 2.)

walkway girder—The girder forming the support of a walkway through the keel or in other localities in a rigid or semirigid airship. (Fig. 4.)

D. TERMS RELATING TO AEROSTATS—Continued

(*c*) DETAILED PARTS AND FITTINGS—Continued

winch suspension—The rigging by means of which the lift and drag of a kite balloon is transmitted from the envelope to the towing or traction cable. (Fig. 2.)

yaw line—A line dropped from the bow of an airship when mooring to the mast to act as a steadying line to prevent yawing and overriding the mast. Also called "bow-steadying line" or "yaw guy." ("Side guy wire," British.)

(*d*) MISCELLANEOUS TERMS

aerodynamic volume—The volume of the form which must be driven through the air. Same as AIR VOLUME.

air volume—The volume of air displaced by the body formed by the outer cover or envelope of an airship. It is this volume which enters into aerodynamic computations. See AERODYNAMIC VOLUME.

air-volume displacement (**or aerodynamic-volume displacement**)—The weight of a mass of air equal to the aerodynamic volume of the airship in N. A. C. A. standard atmosphere at sea level.

buoyancy—The upward air force on an aerostat which is derived from aerostatic conditions. It is equal to the weight of the air displaced.

capacity—The volume of the gas-containing portion of an aerostat.

center of buoyancy—The center of gravity of the volume of the contained gas.

dischargeable weight (**consumable weight**)—All weights which can be consumed or discharged and still leave the airship in safe operating condition with a specified reserve of fuel, oil, water ballast and provisions, and her normal crew.

displacement—The mass of air displaced by the gas used for inflation. It may be expressed as a weight of volume. In the latter case it is usually called "volume."

disposable weight—All weights other than fixed weights, including dischargeable weights contrasted with fixed weights, q. v.

fixed weight—The weight of the hull machinery and all equipment and parts which are fixed in position and nonconsumable. All constant and nonconsumable weights which an airship would carry under all conditions of service (British). Liquids in cooling systems of engines are included.

gas volume—The volume of the contained gas. See CAPACITY.

gross lift—The lift obtained from a volume of buoyant gas equal to the nominal gas capacity of the aircraft. Obtained by multiplying the nominal gas capacity by the lift per unit volume of the gas used for inflation.

lift (**of a gas**)—The difference of density of air and the gas. Both are supposed to be under the same conditions of pressure, temperature, etc.

manometer pressure—The excess of pressure inside the envelope of an aerostat over the atmospheric pressure at a standard reference point. The point of reference for the excess of pressure is usually the bottom of the envelope or gas cell for airships and the level of the basket for kite balloons.

nominal gas capacity—The volume of the envelope of gas cells of an aerostat under certain conditions of pressure and inflation which have been defined. It is rarely the same as the true full volume. This is usually very difficult to determine accurately, especially in the case of rigid airships. Sometimes called "volume."

permeability—The measure of the rate of diffusion of gas through intact balloon fabric; usually expressed in liters of hydrogen per square meter of fabric per 24 hours, under standard conditions of pressure and temperature.

pressure height—The altitude at which the gas cells of a rigid airship are full, or the gas bag of a nonrigid airship is completely full of gas.

purity (**of gas**)—The ratio of the pressure of the hydrogen (or other aerostatic gas) in the container to the total pressure due to all the contained gases.

D. TERMS RELATING TO AEROSTATS—Continued

(*d*) MISCELLANEOUS TERMS—Continued

static ceiling—The altitude in standard atmosphere, at which an aerostat is in static equilibrium after removal of all discharged weights.

volume—The volume of the air displaced by the gas used for inflation.

useful lift—The lift available for carrying fuel, and oil, passengers, cargo, food, and drinking water, guns, ammunition, and bombs. Usually determined by deducting from the gross lift all fixed weights; certain allowances of ballast, fuel, and oil; water; spares and tools; crew and equipment. No standard has as yet been established.

E. TYPES OF AIRPLANES

amphibian—An airplane designed to rise from and alight on either land or water.

biplane—An airplane with two main supporting surfaces placed one above another. (Fig. 1.)

flying boat—A form of seaplane supported, when resting on the surface of the water, by a hull or hulls providing flotation in addition to serving as fuselages. (Fig. 9.) For the central hull type, lateral stability is usually provided by wing-tip floats. The term "boat seaplane" is now obsolete.

landplane—An airplane designed to rise from and alight on the land. (Figs. 1, 6, and 14.)

monoplane—An airplane which has but one main supporting surface, sometimes divided into two parts by the fuselage. (Fig. 6.)

multiplane—An airplane with two or more main supporting surfaces placed one above another.

pusher airplane—An airplane with the propeller or propellers in the rear of the main supporting surfaces. (Figs 9 and 14).

quadruplane—An airplane with four main supporting surfaces, placed one above another.

seaplane.—Any airplane designed to rise from and alight on the water. This general term applies to both boat and float types, though the boat type is usually designated as a "flying boat." (Figs. 9 and 10.)

shipplane—A landplane designed to rise from and alight on the deck of a ship.

tandem airplane—An airplane with two or more sets of wings of substantially the same area (not including the tail unit) placed one in front of the other and on about the same level.

tractor airplane—An airplane with the propeller or propellers forward of the main supporting surfaces. (Figs 1, 6, and 10.)

triplane—An airplane with three main supporting surfaces, placed one above another.

F. TERMS RELATING TO AIRPLANES

(*a*) OPERATION AND MANEUVERS

bank—To incline an airplane laterally, i. e., to rotate it about its longitudinal axis. Right-bank is to incline the airplane with the right wing down.

Also used as a noun to describe the position of an airplane when its lateral axis is inclined to the horizontal.

ceiling:

absolute—The maximum height above sea level at which a given airplane would be able to maintain horizontal flight, assuming standard air conditions.

service—The height above sea level, assuming standard air conditions, at which a given airplane ceases to be able to rise at a rate higher than a small specified one (100 feet per minute in the United States and England). This specified rate may be different in different countries.

dive—A steep descent, with or without power, in which the air speed is greater than the maximum speed in horizontal flight.

glide—A descent with reference to the air at a normal angle of attack and without engine power sufficient for level flight in still air, the propeller thrust being replaced by a component of gravity along the line of flight. Also used as verb.

F. TERMS RELATING TO AIRPLANES—Continued

(*a*) OPERATION AND MANEUVERS—Continued

nose-heavy—The condition of an airplane in normal flight when the distribution of forces is such that, if the longitudinal controls were released, the nose would drop.

pancake, to—To level off an airplane at a greater altitude than normal in a landing, thus causing it to stall and to descend on a steeply inclined path with the wings at a very large angle of attack and without appreciable bank.

power loading—The gross weight of an airplane, fully loaded, divided by the normal brake horsepower of the engine computed for air of standard density, unless otherwise stated

range:

at economic speed—The maximum distance a given aircraft can cover while cruising at the most economical speed and altitude at all stages of the flight.

at full speed—The maximum distance a given aircraft can cover at full speed at sea level.

reverse turn—A rapid maneuver to reverse the direction of flight of an airplane, made by a half loop and half roll.

roll—A maneuver in which a complete revolution about the longitudinal axis is made, the horizontal direction of flight being approximately maintained.

side slipping—Flight in which the lateral axis is inclined and the airplane has a component of velocity in the direction of the lower end of the lateral axis. When it occurs in connection with a turn, it is the opposite of skidding (q. v.).

skidding—Sliding sidewise away from the center of curvature when turning. It is usually caused by banking insufficiently, and is the opposite of side slipping (q. v.).

sky writing—The act of emitting from an aircraft a trail of smoke or other visible substance, the flight of the aircraft being so directed as to cause the trail to assume the form of letters or symbols.

soar—To perform sustained free flight without self-propulsion; it is called "up-current soaring" if performed in ascending air; "dynamic soaring" in other cases.

speed:

critical—The lowest speed of an aircraft at which control can be maintained.

economic—The speed at which the fuel consumption per unit of distance covered in still air is a minimum.

landing—The minimum speed at which an airplane can maintain itself in level flight and still be under adequate control.

minimum—The lowest steady speed which can be maintained by an airplane in level flight at an altitude large in comparison with the dimensions of the wings, with any throttle setting whatever.

spin—A maneuver consisting of a combination of roll and yaw, with the longitudinal axis of the airplane inclined steeply downward. The airplane descends in a helix of large pitch and very small radius, the upper side of the airplane being on the inside of the helix, and the angle of attack on the inner wing being maintained at an extremely large value.

spiral—A maneuver in which an airplane descends in a helix of small pitch and large radius, the angle of attack being within the normal range of flight angles.

stall—The condition of an airplane when from any cause it has lost the air speed necessary for support or control.

tail-heavy—In a heavier-than-air craft the condition in which in normal flight, the tail sinks if the longitudinal control is released, i. e., the condition in which the pilot has to exert a push on the control stick to keep the given attitude.

tail slide—The backward and downward motion, tail first, which certain airplanes may be made to take momentarily after having been brought into a stalling position by a steep climb.

taxi—To run an airplane over the ground or a seaplane on the surface of water under its own power.

F. TERMS RELATING TO AIRPLANES—Continued

(*a*) OPERATION AND MANEUVERS—Continued

warp—To change the form of a wing by twisting it. Warping is sometimes used to maintain the lateral equilibrium of an airplane.

wing-heavy—The condition of an airplane in which (in normal flight) there is a tendency for the right (or left) wing to drop, if the lateral control is released, i. e., the condition in which the pilot has to exert a lateral force on the control stick to keep the lateral axis horizontal.

zoom—To climb for a short time at an angle greater than that which can be maintained in steady flight, the airplane being carried upward at the expense of its kinetic energy. This term is sometimes used as a noun to denote any sudden increase in the upward slope of the flight path.

(*b*) WING PARTS

aileron—A hinged or pivoted movable auxiliary surface of an airplane, usually part of the trailing edge of a wing, the primary function of which is to impress a rolling moment on the airplane. (Fig. 1.)

antidrag wire—A wire designed primarily to resist forces acting parallel to the chord of the wing of an airplane and in the same direction as the direction of flight. It is generally inclosed in the wing. (Fig. 1.)

cabane—A framework for supporting the wings at the fuselage; also applied to the system of trussing used to support overhang in a wing. (Figs. 6, 9, and 10.)

drag strut—A fore-and-aft compression member of the internal bracing system of a wing. (Figs. 1 and 15.)

drag wire—Any wire or cable designed primarily to resist drag forces.

- **internal**—A drag wire concealed inside the wing. (Fig. 1.)
- **external**—A drag wire run from a wing to the fuselage or other part of the airplane. (Fig. 1.)

king-post—The main compression member of a trussing system applied to support a single member subject to bending. (Figs. 4 and 6.)

anding wire—A wire designed primarily to resist forces in the opposite direction to the normal direction of the lift and to oppose the lift wire and prevent distortion of the structure by an overtightening of those members. (Fig. 1.) Sometimes called "antilift" wire.

lift wire—A wire or cable which transmits the lift on the outer portion of the wing of an airplane in toward the fuselage. or nacelle. This wire usually runs from the top of an interplane strut to the bottom of the strut next nearer the fuselage. Sometimes called "flying wire." (Fig. 1.)

main supporting surface—A set of wings, extending on the same general level from tip to tip of an airplane; e. g., a triplane has three main supporting surfaces. The main supporting surfaces include the ailerons, but no other surfaces intended primarily for control or stabilizing purposes.

panel—Where a wing surface comprises several units of construction, these units are designated as panels.

skid fin—A fore-and-aft vertical surface, usually placed above the upper wing, designed to provide vertical keel surface and so to increase lateral stability. (Figs. 9 and 10.)

stagger wire—A wire connecting the upper and lower surfaces of an airplane and lying in a plane substantially parallel to the plane of symmetry. (Also called "incidence wire.") (Fig. 1.)

wing—A general term applied to a whole or a portion of the main supporting surfaces of an airplane but in the latter case is usually qualified as right wing, left wing, upper wing, or lower wing, etc.

F. TERMS RELATING TO AIRPLANES—Continued

(*b*) WING PARTS—Continued

wing rib—A fore-and-aft member of the wing structure of an airplane, used to give the wing section its form and to transmit the load from the fabric to the spars. (Figs. 1 and 15.)

compression rib—A heavy rib designed to have the function of a wing rib and also to act as a strut opposing the pull of the wires in the internal drag truss. (Also called "drag strut.") (Figs. 1 and 15.)

former or false rib—An incomplete rib, frequently consisting only of a strip of wood extending from the leading edge to the front spar, which is used to assist in maintaining the form of the wing where the curvature of the airfoil section is sharpest. (Figs. 1 and 15.)

wing spar—The principal transverse structural member of the wing assembly of an airplane. (Figs. 1 and 15.)

wing truss—The framing by which the wing loads of an airplane are transmitted to the fuselage. It comprises struts, wires, cables, tie rods, and spars.

(*c*) BODY PARTS

bay—The portion of a face of a truss, or of a fuselage, between adjacent bulkheads or adjacent struts or frame positions.

body—The fuselage or hull, or nacelle (including cowling and covering) and nacelle mounting. (Figs. 1, 6, 9, 10, and 14.)

cockpit—The open spaces in which the pilot and passengers are accommodated. (Fig. 1.) When the cockpit is completely housed in, it is called a cabin. (Figs. 1, 6, 9, 10, and 14.)

control stick—The vertical lever by means of which the longitudinal and lateral controls of an airplane are operated. Pitching is controlled by a fore-and-aft movement of the stick, rolling by a side-to-side movement. (Fig. 1.)

cowling—A removable covering which extends over or around the engine and sometimes over a portion of the fuselage or nacelle as well. (Figs. 1, 6, 10, and 14.)

fire wall—A fire-resistance transverse bulkhead, so set as to isolate the engine compartment from the other parts of the structure and thus to reduce the risk from fire in the engine compartment. (Fig. 1.)

fuselage—The structure, of approximately stream line form, to which are attached the wings and tail unit of an airplane. In general it contains the power plant, passengers, cargo, etc. (Figs. 1, 6, and 10.)

longeron—A fore-and-aft member of the framing of an airplane fuselage or nacelle, usually continuous across a number of points of support. (Fig. 1.)

monocoque fuselage—A type of fuselage construction wherein the structure consists of a thin shell of wood, metal, or other material, supported by ribs, frames, belt frames, or bulkheads, but usually without longitudinal members other than the shell itself. The whole is so disposed as to carry the stresses to which the structure is subjected. (Fig. 6.)

nacelle—An inclosed shelter for passengers or for a power plant. A nacelle is usually shorter than a fuselage, and does not carry the tail unit. (Fig. 14.)

rudder—A movable auxiliary airfoil, the function of which is to impress a yawing movement on the aircraft in normal flight. It is usually located at the rear of an aircraft. (Figs. 1, 9, 10, and 14.)

tail boom—A spar or outrigger connecting the tail surfaces and main supporting surfaces. (Fig. 14.)

(*d*) LANDING GEAR PARTS

float—A completely inclosed water-tight structure attached to an aircraft in order to give it buoyancy and stability when in contact with the surface of the water. In float seaplanes the crew is carried in a fuselage or nacelle separate from the float. (Fig. 10.) The term "pontoon" is now obsolete.

F. TERMS RELATING TO AIRPLANES—Continued

(*d*) LANDING GEAR PARTS—Continued

flotation gear—An emergency gear attached to a landplane to permit alighting on the water and to provide buoyancy when resting on the surface of the water.

hull—The portion of a flying boat which furnishes buoyancy when in contact with the surface of the water. It contains accommodations for the crew and passengers, usually incorporating the functions of a float and fuselage in one unit. (Fig. 9.)

landing gear—The understructure which supports the weight of an aircraft when in contact with the surface of the land or water and reduces the shock on landing. There are five common types—boat type, float type, skid type, wheel type, and ski type. (Figs. 1, 6, 9, 10, and 14.) (Amphibian may be a combination of the float or boat type with wheels or skis.)

shock absorber—A device incorporated in the landing gear of an aircraft to reduce the shock imposed on the structure when alighting or taking off.

Shock absorbing devices are usually interposed between the main structure and the wheels, floats, skis, or tail skids, to secure resiliency in landing and taxying. (Fig. 1.)

skid—A runner used as a member of the landing gear and designed to aid the aircraft in landing or taxying.

tail skid—A skid used to support the tail when in contact with the ground. (Figs 1, 6, and 14.)

wing skid—A skid placed near the wing tip and designed to protect the wing from contact with the ground. (Fig. 1.)

step—A break in the form of the bottom of a float or hull, designed to reduce resistance when under way by rapidly reducing the wetted surfaces as speed increases. It also serves to eliminate suction effects.

(*e*) DIMENSIONS AND CHARACTERISTICS

angle of stabilizer setting—The acute angle between the line of thrust of an airplane and the chord of the stabilizer. (Fig. 1.)

angle of wing setting—The acute angle between the plane of wing chord and the line of thrust. It may differ for each wing. (Fig. 1.)

decalage—The acute angle between the wing chords of a biplane or multiplane. (Fig. 1.)

gap—The distance between the planes of the chords of any two adjacent wings, measured along a line perpendicular to the chord of the upper wing at any designated point of its leading edge. (Fig. 1.) Its symbol is G.

landing angle—The acute angle between the line of thrust of an airplane and the horizontal when the airplane is resting on level ground in its natural position. Also called "ground angle." (Fig. 1.)

longitudinal dihedral angle—The difference in angle of wing setting and of stabilizer setting. (Fig. 1.) This angle is positive when the angle of stabilizer setting, referred to the thrust line, is less than the angle of wing setting.

mean chord of a combination of wings—The ratio

$$\frac{c_1\,S_1+c_2\,S_2+c_3\,S_3+\,.\;.\;.\;.}{S_1+S_2+S_3+\,.\;.\;.\;.\;.\;.}$$

where c_1, c_2, c_3, etc., are the mean chords of various wings, and S_1, S_2, S_3, etc., are their areas.

mean chord of a wing—The quotient obtained by dividing the wing area by the extreme dimension of the wing projection at right angles to the chord.

over-all length—The distance from the extreme front to the extreme rear of an aircraft, including the propeller and the tail unit.

F. TERMS RELATING TO AIRPLANES—Continued

(*e*) DIMENSIONS AND CHARACTERISTICS—Continued

overhang—Used in two senses. (1) One-half of the difference in span of any two main supporting surfaces of an airplane. The overhang is positive when the upper of the two main supporting surfaces has the larger span. (Fig. 1.) (2) The distance from the outer strut attachment to the tip of the wings.

span—The maximum distance measured parallel to the lateral axis from tip to tip of an airplane inclusive of ailerons. (Fig. 1.)

stagger—The amount of advance of the leading edge of an upper wing of a biplane, triplane, or multiplane over that of a lower, expressed either as a percentage of gap or in degrees of the angle whose tangent is the percentage just referred to. It is considered positive when the upper wing is forward and is measured from the leading edge of the upper wing along its chord to the point of intersection of this chord with a line drawn perpendicular to the chord of the upper wing at the leading edge of the lower wing, all lines being drawn in a plane parallel to the plane of symmetry. (Fig. 1.)

sweep back—The acute angle between the lateral axis of an airplane and the projection of the axis of the wing on the plane which includes the lateral and longitudinal axes. (Fig. 1.) (The axis of a wing is a line through the centroids of the sections of the wing.)

washin—Permanent warping of the wing which results in an increase in the angle of attack near the tip.

washout—Permanent warping of a wing which results in a decrease in the angle of attack near the tip.

wing-dihedral or dihedral angle—The acute angle between the transverse reference line in the wing surface and the lateral axis of the airplane projected on a plane perpendicular to the longitudinal axis. The dihedral angle is positive when the upper obtuse angle for the two wings is less than 180°. (Fig. 1.)

wing loading—The gross weight of an airplane, fully loaded, divided by the area of the supporting surface. The area used in computing the wing loading should include ailerons but not the stabilizer or elevators.

G. TERMS COMMON TO AEROSTATS AND AIRPLANES

(*a*) PARTS

balanced surface—A control surface which extends on both sides of the axis of the hinge or pivot in such a manner as to reduce the moment of the air forces about the hinge. (Figs. 1, 3, 4, and 5.)

controls—A general term applied to the means provided to enable the pilot to control the speed, direction of flight, attitude, and power of an aircraft.

air controls—The means employed to operate the control surfaces of the aircraft.

engine controls—The means employed to control the power output of the engines. (Control of speed may be effected by the air controls or the engine controls independently, or by either in conjunction with the other.)

control stick—The vertical level by means of which the longitudinal and lateral controls of an airplane are operated. Pitching is controlled by a fore-and-aft movement of the sticks, rolling by a side-to-side movement. (Fig. 1.)

control surface—A movable airfoil designed to be rotated or otherwise moved by the pilot in order to change the attitude of the airplane or airship.

elevator—A movable auxiliary airfoil, the function of which is to impress a pitching moment on the aircraft. The elevator is usually hinged to the stabilizer. (Figs. 1, 3, 4, 5, 6, 9, 10, 13, and 14.)

fin—A fixed surface, attached to a part of the aircraft, parallel to the longitudinal axis, in order to secure stability; for example, tail fin, skid fin, etc. Fins are sometimes adjustable. (Figs. 1, 3, 4, 5, 6, 9, 10, 13, and 14.)

G. TERMS COMMON TO AEROSTATS AND AIRPLANES—Continued

(*a*) PARTS—Continued

fixed fuel tank—A fuel tank which is not intended or fitted to be dropped, as "slip" tanks are.

horn—A short lever attached to a control surface of an aircraft; for example, aileron horn, rudder horn, elevator horn. (Figs. 1, 3, 9, 10, 13, and 14.)

inspection window—A small transparent window fitted in the envelope of a balloon or airship, or in the wing of an airplane, to allow inspection of the interior. (Figs. 1 and 3.)

rigger—One who is employed in assembling and aligning aircraft.

rigging—The assembling, adjusting, and aligning of the parts of an airplane, or the attachment and adjustment of the car, rudders, valves, controls, etc., of an airship.

service tank—A fixed fuel tank near each power unit, into which fuel from other tanks is pumped and from which the fuel supplying the engines is drawn.

slip-fuel tank—A fuel tank which is provided with a device permitting the quick dropping of the tank and contents as a whole in case of an emergency. Fitted on both airships and airplanes.

stabilizer—A normally fixed airfoil whose function is to lessen the pitching motion. It is usually located at the rear of an aircraft and is approximately parallel to the plane of the longitudinal and lateral axes. Also called "tail plane." In aerostats—same as "fin." The lobes of a kite balloon are sometimes referred to as stabilizers. (Figs. 1, 2, 3, 4, 5, 6, 9, 10, 13, and 14.)

tail group (or **tail unit**)—The stabilizing and control surfaces at the rear end of an aircraft, including stabilizer, fin, rudder, and elevator. (Also called "empennage.")

(*b*) PERFORMANCE AND CONDITIONS OF FLIGHT

air speed—The speed of an aircraft relative to the air. Its symbol is V.

controllability—The quality in an airplane which makes it possible for the pilot to change its attitude easily and with the exertion of but little force.

drift—The lateral velocity of an aircraft due to air currents.

drift angle—The horizontal angle between the longitudinal axis of an aircraft and its path relative to the ground.

dynamic factor—The ratio between the load carried by any part of an aircraft when accelerating and the corresponding basic load.

endurance—The maximum length of time an aircraft can remain in the air at a given speed and altitude.

factor of safety—The ratio of the ultimate strength of a member to the maximum probable load in that member in actual use.

flight path—The path of the center of gravity of an aircraft with reference to the earth.

ground speed—The horizontal component of the velocity of an aircraft relative to the earth.

load:

- **dead**—See WEIGHT EMPTY.
- **full**—Weight empty plus useful load. Also called "gross weight."
- **pay**—That part of the useful load from which revenue is derived, viz., passengers and freight.
- **useful**—The crew and passengers, oil and fuel, ballast other than emergency, ordnance, and portable equipment.

load factor—The ratio of any specified load on a member to the corresponding basic load. Generally applied to the ratio of the breaking load to a basic load.

maneuverability—That quality in an aircraft which makes it possible for the pilot to change its attitude rapidly.

performance testing—The process of determining performance characteristics.

rate of climb—The vertical component of the air speed of an aircraft, i. e., its vertical velocity with reference to the air.

G. TERMS COMMON TO AEROSTATS AND AIRPLANES—Continued

(*b*) PERFORMANCE AND CONDITIONS OF FLIGHT—Continued

relative wind—The motion of the air with reference to a body, i. e., its motions as observed by a man at rest on the body. The direction and velocity of the relative wind, therefore, are found by adding two vectors, one being the velocity of the air with reference to the earth, the other being equal and opposite to the velocity of the body with reference to the earth.

wash—The disturbance in the air produced by the passage of an airfoil. Also called the "wake" in the general case for any solid body.

weight empty—The structure, power plant, and fixed equipment of an aircraft. Included in this fixed equipment are the water in the radiator and cooling system, all essential instruments and furnishings, fixed electric wiring for lighting, heating, etc. In the case of the aerostat, the amount of ballast which must be carried to assist in making a safe landing must also be included.

H. MATERIALS AND STRUCTURE

balloon fabric—The finished material, usually rubberized of which balloon or airship envelopes are made.

biased—Plied fabric in which the threads of the plies are at an angle to each other.

parallel—Plied fabric in which the threads of the plies are parallel to each other.

cloth—Fabric delivered by the bleachery or finisher before it has been proofed, doped, or specially treated for aeronautic use.

dope (airplane)—The liquid material applied to the cloth surfaces of airplanes to increase strength, to produce tautness by shrinking, and to act as a filler for maintaining air-tightness.

dope (airship)—The liquid material applied to rubberized airship fabric to increase gas-tightness. In contrast with airplane dope, it does not cause shrinking.

dope (pigmented)—An aircraft dope to which a pigment has been added to make an opaque finish, or to protect it from the effects of sunlight.

duralumin—An alloy of aluminum which is much used in aeronautics, especially for the structure of airships and airplanes. Its chemical composition and physical properties are about as follows:

Copper, 3.5 to 4.5 per cent.
Manganese, 0.4 to 1 per cent.
Magnesium, 0.2 to 0.75 per cent.
Aluminum, 92 per cent, minimum.
Tensile strength, ultimate, 55,000 pounds per square inch.
Tensile strength at elastic limit, 30,000 pounds per square inch.
Elongation of 2 inches at ultimate strength (test specimen ½ inch wide), 18 per cent.
Specific gravity not more than 2.85.

fairing—An auxiliary member or structure whose primary function is to reduce head resistance or drag of the part to which it is fitted (without, in general, contributing strength).

fitting—A generic term for any small part used in the structure of an airplane or airship. If without qualification, a metal part is usually understood. It may refer to other parts, such as "fabric fittings."

gas-cell fabric—The fabric used in gas cells of rigid airships, usually goldbeater's-skin fabric, q. v.

goldbeater's-skin fabric—A gas-containing fabric consisting of a layer of light, fine, strong cloth, usually cotton, to which one or more layers of goldbeater's skins have been cemented. The skins are on the inside and are usually further protected by a coat of fine varnish. Usually used in the gas cells of rigid airships.

laminated wood—A product formed by gluing or otherwise fastening together a number of laminations of wood with the grain substantially parallel. (Differs from plywood in that in the latter the grain of alternate plies is usually crossed at right angles; also, the plies of the latter are usually made up of veneer.)

H. MATERIALS AND STRUCTURE—Continued

panel (aerostat)—The unit piece of fabric of which the envelope or outer cover of an aerostat is made. Panels may be assembled into sections, gores, or rings, according to the method of manufacture followed.

In rigid airships the area bounded by two adjacent longitudinals and two adjacent transverses is often referred to as a "panel." This is a structural panel and the expression is borrowed from structural engineers.

plywood—A product formed by gluing together two or more layers of veneer. The alternate plies are usually placed with grain at right angles to the adjacent plies.

proofing—Material incorporated in the fabric of an aerostat at the time of manufacture, to increase its resistance to the weather and/or to prevent the passage of gas (or decrease its permeability).

stay—A wire or other tension member; for example, the stays of the wing and body trussing. (Fig. 1.)

strut—A compression member of a truss frame. For instance, the vertical members of the wing truss of a biplane (interplane struts) and the short vertical and horizontal members separating the longerons (q. v.) in the fuselage. (Fig. 1.)

veneer—Thin sheets of wood, either sliced with a knife or sawed.

wire—In aeronautics, refers specifically to drawn solid wire.

I. AIRPORT AND LANDING FIELD TERMS

airport—A locality, either of water or land, which is adapted for the landing and taking off of aircraft and which provides facilities for shelter, supply, and repair of aircraft; or a place used regularly for receiving or discharging passengers or cargo by air.

airship station—The complete assembly of sheds, masts, gas plants, shops, landing fields and related equipment required to operate airships and supply their needs. A station may include all or a part of the items enumerated. The base from which air ships are operated.

apron—A hard surface area of considerable extent immediately in front of the entrance of a hangar or aircraft shelter which is used for the handling of aircraft or for repair in clear weather.

balloon bed—A mooring place on the ground for a captive balloon.

dock—A term sometimes applied to an airship shed.

docking rail—A rail or a guide, constructed on the landing field and extending into the shed which supplies a means for holding the lateral pull of an airship's docking or handling lines. The pull is transmitted to the rails from wheeled cars or trolleys which are fitted on or in the rails. Usually two rails are fitted at the greatest distance apart which will permit them to be run into the shed.

docking trolley—A car or trolley fitted on (or in) docking rails to transmit the pull of an airship docking line. It is fitted with wheels having antifriction bearings so it can move freely in the rail. Usually some sort of quick-release device for letting go the line is also fitted.

emergency landing field—A locality, either of water or land, which is adapted for the landing and taking off of aircraft, but which is not equipped with facilities for shelter, supply, and repair of aircraft and is not used regularly for the receipt or discharge of passengers or cargo by air.

ground cloth—Canvas placed beneath an aerostat for its protection during inflation and deflation.

ground gear—The gear, or equipment, necessary for the landing and handling of an airship on the ground.

hangar—A shelter for housing aircraft. More properly applied to heavier-than-air craft.

landing crew—A detail of men necessary for the landing and handling of an airship on the ground. A "ground crew."

landing field—A field of such a size and nature as to permit of aircraft landing and taking off in safety. It may or may not be part of an airport or air station.

I. AIRPORT AND LANDING FIELD TERMS—Continued

landing T—A large symbol shaped like a capital T which is laid out on a landing field or on the top of a building to guide operators of aircraft in landing and taking off.

mast main mooring line—A line led from the main winch of a mooring mast through the mooring attachment at the top of the mast and carried out to a point on the ground well to leeward of the mast. The airship's main mooring line is attached to this line and the airship is hauled to the mast by means of the joined lines. Sometimes called "ground wire" (British).

mast yaw line—One of the lines led from a winch at the base of the mooring mast through snatch blocks and carried out to leeward of the mast. The airship's yaw lines are attached to these lines. The snatch blocks are fixed to anchorages selected so that the joined lines tend to keep the airship into the wind and prevent her overriding the mast. These lines are also sometimes called "mast yaw guys" or "mast bow-steadying lines."

mooring drag—A movable and/or variable weight suspended from the after part of an airship's structure while moored at a mast to aid in restraining the vertical and lateral motions of the stern of the airship.

mooring mast—A mast or tower at the top of which there is mounted a fitting, so that the bow of an airship may be secured. It is usually provided with a ladder or staircase and a platform at the top, so that crew and passengers may enter or leave the airship, and also with piping for the supply of fuel, gas, and water. Sometimes called "mooring tower."

overhead suspension—A line leading from the roof of an airship shed and arranged to sustain the whole or a part of the weight of the structure of an airship when it is docked.

ram—The combination of tubes and springs which is mounted in gimbals at the top of a mooring mast. It consists of an outer tube which carries the gimbal mounting and within which slides an inner tube. The upper end of the inner tube carries the hollow cone which receives the airship's mooring cone and which is fitted to revolve freely. The inner tube can slide down into the outer tube and compress heavy springs, thus easing the shock when the mooring is made.

shed—A shelter for housing airships.

shore—A structural member for supporting the structure of a rigid or semirigid airship during building or docking, used in conjunction with (or without) a cradle.

snatch-block anchorage—An anchorage set in the ground for a snatch block used with a yaw line from a mooring mast. The anchorages may be of concrete or timber and are usually arranged at equal intervals around the circumference of a circle whose center is the mast; may also be applied to any anchorage for a snatch block used in hauling down an airship or kite balloon.

three-point mooring—A system of mooring an airship. It consists primarily of three lines running from a mooring ring (or point) on the airship to three points on the ground. These points are usually at the vertices of an equilateral triangle. The lines may be secured to anchorages at the points or run over snatch blocks and to equalizing gear. The endeavor is to moor the airship in such a manner that the dynamic lift due to the relative wind shall keep the airship at a constant height from the ground. It may be considered as a substitute for a mooring mast, usually an emergency substitute.

J. AERODYNAMIC TERMS

(*a*) AXES, ANGLES, FORCES, ETC.

aerodynamic volume (airship)—The volume of the form which must be driven through the air. Same as "air-volume."

aileron angle—The angular displacement of an aileron from its neutral position. It is positive when the trailing edge of the aileron is below the neutral position.

angle of attack—The acute angle between the chord of an airfoil and its direction of motion relative to the air. (This definition may be extended to other bodies than airfoils.) Its symbol is α.

J. AERODYNAMIC TERMS—Continued

(*a*) AXLES, ANGLES, FORCES, ETC.—Continued

angle of pitch—The acute angle between two planes defined as follows: One plane includes the lateral axis of the aircraft and the direction of the relative wind; the other plane includes the lateral axis and the longitudinal axis. (In normal flight the angle of pitch is, then, the angle between the longitudinal axis and the direction of the relative wind.) This angle is denoted by Θ and is positive when the nose of the aircraft has risen.

angle of roll, or angle of bank—The acute angle through which an aircraft must be rotated about its longitudinal axis in order to bring its lateral axis into a horizontal plane. This angle is denoted by Φ and is positive when the left wing is higher than the right.

angle of yaw—The acute angle between the direction of the relative wind and the plane of symmetry of an aircraft. This angle is denoted by Ψ and is positive when the aircraft has turned to the right.

attitude—The position of an aircraft as determined by the inclination of its axes to some frame of reference. If not otherwise specified, this frame of reference is fixed to the earth.

axes of an aircraft—Three fixed lines of reference, usually centroidal and mutually perpendicular. The longitudinal axis in the plane of symmetry, usually parallel to the axis of the propeller is called the longitudinal axis; the axis perpendicular to this in the plane of symmetry is called the normal axis; and the third axis perpendicular to the other two is called the lateral axis. In mathematical discussions, the first of these axes, drawn from front to rear, is called the X axis; the second, drawn upward, the Z axis; and the third, running from right to left, the Y axis.

basic load—The load on an aircraft when it is at rest or in a condition of unaccelerated rectilinear flight (for purposes of stress analysis).

critical angle—An angle of attack at which the flow about an airfoil changes abruptly with corresponding abrupt changes in the lift and drag.

cross-wind force—The component perpendicular to the lift and to the drag of the total air force on an aircraft or any part thereof. Its symbol is C and its absolute coefficient C_C is defined by

$$C_C=\frac{C}{qS}$$

where q is the impact pressure $(=\frac{1}{2}\rho V^2)$ and S is the effective area of the surface upon which the air force acts.

downwash angle—The angle through which an air stream is deflected by any lifting surface of an airplane. It is measured in a plane parallel to the plane of symmetry, and is denoted by the symbol ϵ.

drag—The component parallel to the relative wind of the total air force on an aircraft or airfoil. Its symbol is D.

The "absolute drag coefficient" is C_D as defined by the equation

$$C_D=\frac{D}{qS}$$

in which D is the drag, q is the impact pressure $(=\frac{1}{2}\rho V^2$ and S is the effective area of the surface upon which the air force acts.

In the case of an airplane, that part of the drag due to the wings is called "wing drag"; that due to the rest of the airplane is called "structural drag" or "parasite resistance."

induced—That portion of the wing drag induced by, or resulting from, the generation of the lift.

profile—That portion of the wing drag which is due to friction and turbulence in the fluid and which would be absent in a nonviscous fluid.

J. AERODYNAMIC TERMS—Continued

(*a*) AXES, ANGLES, FORCES, ETC.—Continued

dynamic lift—The lift impressed on an aerostat by aerodynamic forces.

dynamic load—Any load due to accelerations of an aircraft, and therefore proportional to its mass.

dynamic (or impact) pressure—The product $\frac{1}{2}\rho V^2$, where ρ is the density of the air and V is the relative speed of the air. It is the quantity measured by most air-speed instruments. Its symbol is q.

dynamic trim—Trim (or trimming) due to dynamic conditions or their change.

elevator angle—The angular displacement of the elevator from its neutral position. It is positive when the trailing edge of the elevator is below the neutral position.

lift—That component of the total air force on an aircraft or airfoil which is perpendicular to the relative wind and in the plane of symmetry. It must be specified whether this applies to a complete aircraft or to parts thereof. In the case of an airship, this is often called "dynamic lift." Its symbol is L.

The "absolute lift coefficient" is C_L as defined by the equation

$$C_L=\frac{L}{qS}$$

in which L is the lift, q is the impact pressure $\left(=\frac{1}{2}\rho V^2\right)$ and S is the effective area of the surface upon which the air force acts.

minimum gliding angle—The acute angle between the horizontal and the most nearly horizontal path along which an airplane can descend steadily in still air when the propeller is giving no thrust.

Reynolds Number—A name given the fraction, $\rho\frac{Vl}{\mu}$, in which

ρ is the density of the fluid;
V is the relative velocity of the fluid;
l is the linear dimension of the body;
μ is the coefficient of viscosity of the fluid.

rudder angle—The acute angle between the rudder and the plane of symmetry of the aircraft. It is positive when the trailing edge has moved to the left with reference to the normal position of the pilot.

rudder torque—The twisting moment exerted by the rudder on the fuselage. The product of the rudder area by the distance from its center of area to the axis of the fuselage may be used as a relative measure of rudder torque.

skin friction—The tangential component of the fluid force at a point on a surface.

static lift (aerostat)—The resultant upward force on an aerostat at rest obtained by multiplying the actual volume of the air displaced by the density of the air and subtracting the weight of the contained gas. (The volume of the air displaced, multiplied by the difference of density of the air and the contained gas.)

static trim—Trim (or trimming) due to static conditions or their change.

zero-lift angle—The angle of attack of an airfoil when its lift is zero.

zero-lift line—A line through the trailing edge of an airfoil section parallel to the direction of the wind when the lift is zero.

(*b*) MISCELLANEOUS TERMS

airfoil—Any surface designed to be projected through the air in order to produce a useful dynamic reaction.

airfoil section (or profile)—A cross section of an airfoil made by a plane parallel to a specified reference plane. A line perpendicular to this plane is called the axis of the airfoil.

J. AERODYNAMIC TERMS—Continued

(*b*) MISCELLANEOUS TERMS—Continued

aspect ratio—The ratio of span to mean chord of an airfoil; i. e., the ratio of the square of the maximum span to the total area of an airfoil.

camber—The rise in the curve of an airfoil section from its chord, usually expressed as the ratio of the departure of the curve from the chord to the length of the chord. "Upper camber" refers to the upper surface of an airfoil and "lower camber" to the lower surface; "mean camber" is the mean of these two.

center of pressure coefficient—The ratio of the distance of the center of pressure from the leading edge to the chord length.

center of pressure of an airfoil section—The point in the chord of an airfoil section, prolonged if necessary, which is at the intersection of the chord and the line of action of the resultant air force. Its abbreviation is *C. P.*

chord (of an airfoil section)—The line of a straight edge brought into contact with the lower surface of the section at two points; in the case of an airfoil having double convex camber, the straight line joining the leading and trailing edges. (These edges may be defined, for this purpose, as the two points in the section which are farthest apart.) (Fig. 1.) The line joining the leading and trailing edges should be used also in those cases in which the lower surface is convex except for a short flat portion.

The method used for determining the chord should always be explicitly stated for those sections with regard to which ambiguity seems likely to arise.

chord length—The length of the projection of the airfoil section on its chord. Its symbol is c.

leading edge—The foremost edge of an airfoil or propeller blade. Also called "entering edge." (Fig. 1.)

span (airfoil)—The lateral dimension of an airfoil; i. e., its dimension perpendicular to its chord. Its symbol is b.

streamline—The path of a small portion of a fluid relative to a solid body with respect to which the fluid is moving. The term is commonly used only of such flows as are not eddying, but the distinction should be made clear by the context.

streamline flow—Steady flow past a solid body; i. e., a flow in which the direction at every point is independent of time.

streamline form—A solid body which produces approximately streamline flow.

trailing edge—The rearmost edge of an airfoil or propeller blade. (Fig. 1.)

wind tunnel—An elongated chamber, usually a tube divergent at the ends, through which a steady air stream may be drawn or forced. Models of airfoils, of aircraft, or of propellers may be placed in the middle portion of the tunnel, called the experiment chamber or working section, and supported by suitable balances placed outside the air stream, so that the forces, moments, etc., due to the moving air may be measured.

(*c*) STABILITY THEORY

damping factor—The factor $e^{-\lambda t}$ in the equation of damped harmonic motion

$$s = Ae^{-\lambda t} \sin pt.$$

divergence—A motion in which, after a disturbance from equilibrium, the body departs continuously, without oscillations, from its original state of motion.

logarithmic decrement—The natural logarithm of the ratio of two successive amplitudes in a damped harmonic motion. It is equal to the product λT where λ is the coefficient appearing in the damping factor of damped harmonic motion and T is the period of the motion.

period—The time taken for a complete oscillation.

J. AERODYNAMIC TERMS—Continued

(c) STABILITY THEORY—Continued

phugoid oscillation—A long-period oscillation characteristic of the disturbed longitudinal motion of an aircraft. This is referred to when it is said that an aircraft "hunts."

resistance derivatives—Quantities expressing the variation of the forces and moments on aircraft due to disturbance of steady motion. They form the experimental basis of the theory of stability, and from them the periods and damping factors of aircraft can be calculated. In the general case, there are 18 translatory and 18 rotary derivatives.

rotary—Resistance derivatives expressing the variation of moments and forces due to small changes in the rotational velocities of the aircraft.

translatory—Resistance derivatives expressing the variation of moments and forces due to small changes in the translational velocities of the aircraft.

righting moment (**or restoring moment**)—A moment which tends to restore an aircraft to its previous attitude after any small rotational displacement.

stability—That property of a body which causes it, when disturbed from a condition of equilibrium or steady motion, to develop forces or moments which tend to restore the body to its original condition.

automatic—Stability dependent upon movable control surface automatically operated by mechanical means.

inherent—Stability of an aircraft due solely to the disposition and arrangement of its fixed parts; i. e., that property which causes it, when disturbed, to return to its normal attitude of flight without the use of controls or the interposition of any mechanical devices.

static—Stability of such a character that, if the airplane is displaced slightly from its normal attitude by rotation about an axis through its center of gravity (as may be done in wind-tunnel experiments), moments come into play which tend to return the airplane toward its original attitude.

dynamic—Stability of such a character that, if the airplane is displaced from steady motion in flight, it tends to return to that steady state of motion, the oscillations due to restoring moments being damped out.

In a general way, the difference between static stability and dynamic stability is that the former depends on restoring moments alone, while the latter includes the action of damping factors.

longitudinal—Stability with reference to disturbances in the plane of symmetry; i. e., disturbances involving pitching and variation of the longitudinal and normal velocities.

directional—Stability with reference to rotations about the normal axis; i. e., an airplane possesses directional stability in its simplest form if a restoring moment comes into action when it is given a small angle of yaw. Owing to symmetry, directional stability is closely associated with lateral stability.

lateral—Stability with reference to disturbances involving rolling, yawing, or side slipping; i. e., disturbances in which the position of the plane of symmetry of the aircraft is affected.

spiral instability—A type of instability inherent in certain airplanes which becomes evident when the airplane, as a result of a yaw, assumes too great a bank and side slips; the bank continues to increase and the radius of the turn to decrease.

stable oscillation—An oscillation whose amplitude does not increase.

unstable oscillation—An oscillation whose amplitude increases continuously until an attitude is reached from which there is no tendency to return toward the original attitude, the motion becoming a steady divergence.

K. PROPELLER TERMS

(a) MISCELLANEOUS

blade back—The side of a propeller blade which corresponds to the upper surface of an airfoil.

blade face—The surface of a propeller blade which corresponds to the lower surface of an airfoil. Sometimes called "thrust face" or "driving face."

propeller:

adjustable pitch—A propeller whose blades are so attached to the hub that they may be set to any desired pitch when the propeller is stationary.

controllable pitch or variable pitch—A propeller whose blades are so mounted that they may be turned about their axis to any desired pitch while the propeller is in rotation.

propeller blade—See blade back, blade face, blade width ratio. (Fig. 1.)

propeller boss—The central portion of a propeller in which the hub is formed or mounted. (Fig. 1.)

propeller hub—The metal fitting inserted or incorporated in or with a propeller for the purpose of mounting it on the propeller or engine shaft. (Fig. 1.)

propeller root—That part of the propeller blade near the boss. (Fig. 1.)

pusher propeller—A propeller mounted to the rear of the engine or propeller shaft. (It is usually behind the wing cell or nacelle.) (Figs. 9 and 14.)

spinner—A fairing of approximately conical or paraboloidal form, which is fitted coaxially with the propeller boss and revolves with the propeller. (Fig. 1.)

tipping (propeller)—A sheet metal (or equivalent) protective covering of the blade of a propeller near the tip, extended a short distance along the trailing edge and a considerable distance along the leading edge. (Fig. 1.)

tractor propeller—A propeller mounted on the forward end of the engine or propeller shaft. (It is usually forward of the fuselage or wing nacelle.) (Figs. 1, 6, and 10.)

(b) AERODYNAMICAL

angle of propeller blade—The acute angle between the chord of a propeller section and a plane perpendicular to the axis of rotation of the propeller. Usually called "blade angle."

aspect ratio of propeller blade—Half the ratio of propeller diameter to maximum blade width.

blade-width ratio—The ratio of the developed width of a propeller blade at any point to the circumference of the circle whose radius is the distance of that point from the propeller axis.

effective helix angle—The angle of the helix described by a particular point on a propeller blade as the airplane moves forward through air otherwise undisturbed. It is equal to the angle whose tangent is the ratio of the velocity of flight to the product of the four quantities: 2π, r (the distance from the axis to the point in question) and n (the number of revolutions per second), i. e.

$$\Phi = \tan^{-1}\left(\frac{V}{2\pi rn}\right)$$

effective thrust—The net driving force delivered by a propeller when mounted on an airplane; i. e., the actual thrust given by the propeller as mounted on the airplane minus any increase of resistance of the airplane produced by the action of the propeller.

indraft (inflow)—The flow of air from in front of the propeller into the blades.

pitch of a propeller:

effective—The distance which an aircraft advances along its flight path for one revolution of the propeller. Its symbol is p_e.

geometrical—The distance which an element of a propeller would advance in one revolution, if it were moving along a helix of slope equal to its blade angle.

mean geometrical—The mean of the geometrical pitches of the several elements. Its symbol is p_g.

standard—The geometrical pitch taken at two-thirds of the radius. Also called "nominal pitch." Its symbol is p_s.

K. PROPELLER TERMS—Continued

(*b*) AERODYNAMICAL—Continued

pitch of a propeller—continued.

zero thrust—The distance which a propeller would have to advance in one revolution in order that there might be no thrust. Also called "experimental mean pitch." Its symbol is p_v.

zero torque—The distance which a propeller would have to advance in one revolution in order that the torque might be zero. Its symbol is p_a.

pitch ratio—The ratio of the pitch (geometrical, unless otherwise stated) to the diameter. p/D.

pitch speed—The product of the mean geometrical pitch by the number of revolutions of the propeller in unit time; i. e., the speed the aircraft would make, if there were no slip.

propeller area, projected—The total area in the plane perpendicular to the propeller shaft swept by the propeller, excepting the portion covered by the boss and that swept by the root of the blade. This portion is usually taken as extending 0.2 of the maximum radius from the axis of the shaft.

propeller-blade area—The area of the blade face, exclusive of the boss and the root, i. e., of a portion which is usually taken as extending 0.2 of the maximum radius from the axis of the shaft.

propeller-camber ratio—The ratio of the maximum thickness of a propeller section to its chord.

propeller-disk area, total—The total area swept by a propeller; i. e., the area of a circle having a diameter equal to the propeller diameter.

propeller efficiency—The ratio of thrust power to power input of a propeller. Its symbol is η.

propeller interference—The amount by which the torque and thrust of a propeller are changed by the modification of the air flow in the slip stream produced by bodies placed near the propeller such as engine, radiator, etc.

propeller-load curve—A curve representing the engine power necessary to drive any given propeller at various speeds. The power required varies approximately as the cube of the speed in R. P. M. provided the ratio $\frac{V}{N\,D}$ remains constant.

propeller rake—The mean angle which the line joining the centroids of the sections of a propeller blade makes with a plane perpendicular to the axis.

propeller section—A cross section of a propeller blade made at any point by a plane parallel to the axis of rotation of the propeller and tangent at the centroid of the section to an arc drawn with the axis of rotation as its center.

propeller thrust—The component parallel to the propeller axis of the total air force on the propeller. Its symbol is T.

propeller torque—The moment applied to the propeller by the engine shaft. Its symbol is Q.

propeller-width ratio, total—The product of blade width ratio at the point of maximum blade width by number of blades.

propulsive efficiency—The ratio of the product of effective thrust and flight speed to the actual power input to the propeller as mounted on the airplane, consistent units being used throughout.

race rotation—The rotation, produced by the action of the propeller, of the stream of air passing through or influenced by the propeller.

slip—The difference between the mean geometrical pitch and the effective pitch. Slip may be expressed as a percentage of the mean geometrical pitch or as a linear dimension.

slip function—The ratio of speed of advance through the undisturbed air to the product of propeller diameter by the number of revolutions in unit time, i. e., $\frac{V}{N\,D}$. The slip function is the primary factor controlling propeller performance. It is π times the ratio of forward speed to the tip speed of the propeller.

slip stream—The stream of air driven astern by the propeller. (The indraft is sometimes included also.)

static thrust—The thrust developed by a propeller when rotating at a fixed point.

L. INSTRUMENTS AND AUXILIARY APPARATUS

accelerometer—An instrument for indicating, measuring, or recording accelerations.

air log—An instrument for measuring the linear travel of an aircraft relative to the air. One form consists of a windmill with a revolution counter.

air-speed meter:

air-speed indicator—An instrument for indicating the speed of an aircraft relative to the air. It is actuated by the pressure developed in a suitable pressure nozzle or against a suitable obstruction and is graduated to give true air speed at a standard air density. The speed indicated by the instrument is termed the "indicated air speed." (The indicated speed is a direct measure of the lift or drag exerted on the airplane at any altitude. Stalling at all altitudes occurs for the same value of the indicated speed.)

true air-speed meter—An instrument for measuring the true speed of an aircraft relative to the air. The Biram and Robinson anemometers are of this type.

altigraph—An altimeter equipped with recording mechanism. Present instruments are of the aneroid type. The chart, driven by clockwork, is usually graduated in feet or meters in accordance with some empirical or arbitrary pressure-temperature-altitude formula. In other words, it is a barograph whose scale is designed to read heights.

altimeter—An instrument for measuring or indicating the elevation of an aircraft above a given datum plane.

anemometer—An instrument for indicating or measuring the speed of an air stream.

aneroid altimeter—An altimeter, the indications of which depend on the deflection of a pressure-sensitive element. The graduations of the dial correspond to an empirical or arbitrary pressure-temperature-altitude formula.

ballonet-fullness indicator—An instrument for indicating the volume of air in a ballonet.

barograph—An instrument for recording the barometric or static pressure of the atmosphere.

drift bar—A part of a drift meter or other instrument for indicating the apparent direction of motion of the ground relative to the fore-and-aft axis of the aircraft. It usually consists of a wire or arm which can be set along this direction of motion. Cf. drift.

drift meter—An instrument for measuring the angle between the fore-and-aft axis of an aircraft and its path over the ground. One form consists of a drift bar provided with a suitable angular scale. Cf. drift. The instrument is graduated to read correctly when it is level.

electrical-capacity altimeter—An altimeter, the indications of which depend on the variation of an electrical capacity with distance from the earth's surface.

engine altimeter—An altimeter for indicating the altitude corresponding to the pressure produced in the intake manifold of a supercharged engine.

flight indicator—An instrument in which a lateral inclinometer, a fore-and-aft inclinometer, and a turn indicator are combined to form a compact unit.

flight recorder—An instrument for recording certain elements of the performance of an aircraft.

gas-cell alarm—A device, fitted adjacent to a gas cell, which indicates or warns when a predetermined limiting pressure has been reached in the gas cell. Also called "pressure alarm."

ground-speed meter—An instrument for measuring the speed of an aircraft relative to the ground. In present types of instruments some reference line in the instrument must first be set parallel to the apparent direction of motion of the aircraft with reference to the ground before the speed measurement is made. This is usually accomplished by the use of a drift meter, the adjustment of which automatically orients the ground-speed meter properly. Thus both the magnitude and direction of the motion of the aircraft with reference to the ground are obtained.

gyroscopic turn indicator—A turn indicator dependent on gyroscopic action.

inclinometer—An instrument for indicating the attitude of an aircraft. Inclinometers are termed fore-and-aft, lateral, or universal, according as they indicate inclination on the vertical plane through the fore-and-aft axis, or in the vertical plane through the lateral axis, or in both planes, respectively.

L. INSTRUMENTS AND AUXILIARY APPARATUS—Continued

induction compass—A compass, the indications of which depend on the current generated in a coil revolving in the earth's magnetic field.

absolute—An instrument which indicates the attitude of an aircraft with reference to the vertical. The indications of instruments of this type usually depend on gyroscopic action.

relative—An instrument which indicates the attitude of an aircraft with reference to apparent gravity; i. e., to the resultant of the acceleration of the aircraft and that due to gravity.

kymograph—An instrument for recording the angular oscillations of an aircraft in flight with respect to axes fixed in space. The reference direction is usually given by a gyroscope or beam of sunlight.

leak detector—An instrument which detects the presence of hydrogen and other light gases in the air and which can be adapted to find leaks in a container inflated with such a gas.

mechanical stabilizer—A mechanical device to prevent an aircraft from departing from a condition of steady motion, or, in case such a motion is disturbed, to restore it to its steady state. Includes gyroscopic stabilizers, pendulum stabilizers, inertia stabilizers, etc.

optical altimeter—An altimeter, the indications of which depend on the manipulation of a suitable optical system.

pitch indicator—An instrument for indicating the existence of a pitching velocity of an aircraft. Cf. turn indicator.

Pitot tube—A cylindrical tube with an open end which is pointed upstream (i. e., so that the air meets the instrument head-on or is met head-on by the instrument). When the aircraft is flying less than about 200 miles per hour, the instrument measures the impact pressure. When used on aircraft, it is usually associated either with a closed coaxial tube surrounding it or with a closed tube placed near it and parallel to it, the combination being termed a Pitot-static tube. The associated tube has perforations in its side so that it is subjected to static pressure, as distinct from impact pressure. The speed of the fluid can be determined from the difference between the impact pressure and the static pressure, as read by a suitable gauge. (Fig. 7.) In common terminology, the Pitot-static combination, as above, is often termed simply a Pitot tube or Pitot.

power Venturi—A Venturi tube used to operate gyroscopic turn indicators and other instruments.

pressure nozzle—An instrument which, in combination with a gauge, is used to measure the indicated speed of an aircraft relative to the air. It may be a Pitot-static or a Venturi tube, or a combination of a Pitot tube and a Venturi tube.

sound-ranging altimeter—An altimeter, the indications of which depend on the measurement of the time required for a sound wave to travel from the aircraft to the earth and back.

speed-indicating Venturi—A Venturi tube may be combined with a Pitot tube or with a tube giving static pressure to form a pressure nozzle which may be used to determine the indicated speed of an aircraft through the air. The pressure difference is measured by a suitable gauge.

static turn indicator—A turn indicator actuated by the difference in pressure between static tubes mounted near the wing tips equidistant from the plane of symmetry and in a plane parallel to the lateral axis.

statoscope—An instrument for detecting minute changes of altitude of an aircraft. The indications of the instrument usually depend on small changes of the static pressure of the air.

superheat meter—An instrument for measuring the difference in temperature between the gas in a gas container of a lighter-than-air craft and the surrounding air.

thermograph—An instrument for recording temperature.

turn indicator—An instrument for indicating the existence of an angular velocity of turn of an aircraft about the normal axis. In horizontal flight it indicates the presence of a yawing velocity. "Turn meter" is the term applied to certain types.

L. INSTRUMENTS AND AUXILIARY APPARATUS—Continued

Venturi tube—A short tube with flaring ends and a narrow or constricted section between them, into which a side tube opens. When fluid flows through the Venturi, there is a reduction of pressure in the constricted section, the amount of the reduction being a function of the velocity of flow. (Fig. 8.)

vertimeter—A device for indicating the rate of rise and fall of an aerostat, usually a special form of statoscope. A rate-of-climb meter serves the same purpose, although of a different form.

water-recovery apparatus—Apparatus carried on an airship for condensing and recovering the water contained in the exhaust gases of internal-combustion engines, in order to avoid the necessity of valving gas as the fuel is consumed.

water-recovery condenser—That part of the water-recovery apparatus which is devoted to the condensing of water in the exhaust gases. It may consist of a number of metal tubes or of a fabric box with appropriate inlets, outlets, and baffles.

windmill—An air-driven screw used to drive auxiliary apparatus on an aircraft.

yawmeter—An instrument for measuring the angle of yaw.

M. ENGINE TERMS

(*a*) TYPES OF ENGINES

barrel-type engine—An engine having its cylinders arranged equidistant from and parallel to the main shaft.

inverted engine—An engine having its cylinders below the crankshaft.

left-hand engine—An engine whose propeller shaft, to an observer facing the propeller from the antipropeller end of the shaft, rotates in a counterclockwise direction.

left side (engine)—That side which, to an observer looking from the antipropeller end toward the propeller end, lies on the left-hand side.

radial engine—An engine having stationary cylinders arranged radially around a common crankshaft.

right-hand engine—An engine whose propeller shaft, to an observer facing the propeller from the antipropeller end of the shaft, rotates in a clockwise direction.

right side (engine)—That side which, to an observer looking from the antipropeller end toward the propeller end, lies on the right-hand side.

rotary engine—An engine having revolving cylinders arranged radially around a common fixed crankshaft.

supercharged engine—An engine with mechanical means for increasing the cylinder charge beyond that normally taken in at the existing atmospheric pressure and temperature.

vertical engine—An engine having its cylinders arranged vertically above the crankshaft.

V-type engine—An engine having its cylinders arranged in two rows, forming, in the end view, the letter "V."

W-type engine—An engine having its cylinders arranged in three rows, forming, in the end view, the letter "W." Sometimes called the "broad-arrow type."

(*b*) SUPERCHARGERS

supercharger—A mechanical device for supplying the engine with a greater weight of charge than would normally be induced at the prevailing atmospheric pressure and temperature.

- **centrifugal type**—A supercharging device equipped with one or more rotating impellers generating centrifugal force which is utilized for the compression and the transmission of the air against resistance.
- **positive-driven type**—A supercharger driven at a fixed speed ratio from the engine shaft by gears or other positive means.
- **rotary-blower type**—A supercharging device comprising one or more relatively slow-speed rotors revolving in a stationary case in such a way as to provide a positive displacement.
- **turbo type**—A supercharger driven by a turbine operated by the exhaust gases from the engine.

M. ENGINE TERMS—Continued

(*c*) Miscellaneous Terms

brake mean effective pressure—The net unit pressure which, if applied during the power strokes to the pistons of an engine having no mechanical losses, would produce the given brake horsepower at the stated speed.

dry weight of an engine—The weight of the engine, including carburetor and ignition systems complete, propeller hub assembly, reduction gears, if any, but excluding exhaust manifolds, oil and water. If the starter is built into the engine as an integral part of the structure, its weight shall be included.

fixed power-plant weight for a given airplane.—The weight of the engine, including ignition, carburetor and induction systems complete, propeller and hub, exhaust manifolds, radiator and water, *if used*, with all interconnecting wires, controls, tanks, and pipes, lubricating oil temperature regulators, *the oil contained in the engine crank case*, and the starting gear attached to the engine, but excluding fuel, oil, and engine instruments.

maximum horsepower of an engine—The maximum horsepower which an engine can develop.

maximum revolutions—The number of revolutions per minute corresponding to the maximum horsepower.

rated horsepower of an engine—The average horsepower developed by an engine of a given type in passing the standard 50-hour endurance test.

rated revolutions—The number of revolutions corresponding to the rated horsepower.

specific fuel (or oil) consumption—The weight of fuel (or oil) consumed per brake horsepower-hour.

weight per horsepower—The dry weight of an engine divided by the rated horsepower.

REPORT No. 240

NOMENCLATURE FOR AERONAUTICS

By The National Advisory Committee for Aeronautics

PART III

AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	sec	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/sec		horsepower	HP.
Speed		km/hr		mi./hr	M. P. H.
		m/sec		ft./sec	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $= mg$

g, Standard acceleration of gravity = 9.80665 m/sec.^{2} = 32.1740 ft./sec.^{2}

m, Mass, $= \frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} sec.^{2}) at 15° C and 760 mm = 0.002378 (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m^3 = 0.07651 lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from *c. g.* to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $= \frac{1}{2} \rho V^2$

L, Lift, absolute coefficient $C_L = \frac{L}{qS}$

D, Drag, absolute coefficient $C_D = \frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C = \frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to to thrust line.

γ, Dihedral angle.

$\frac{\rho Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

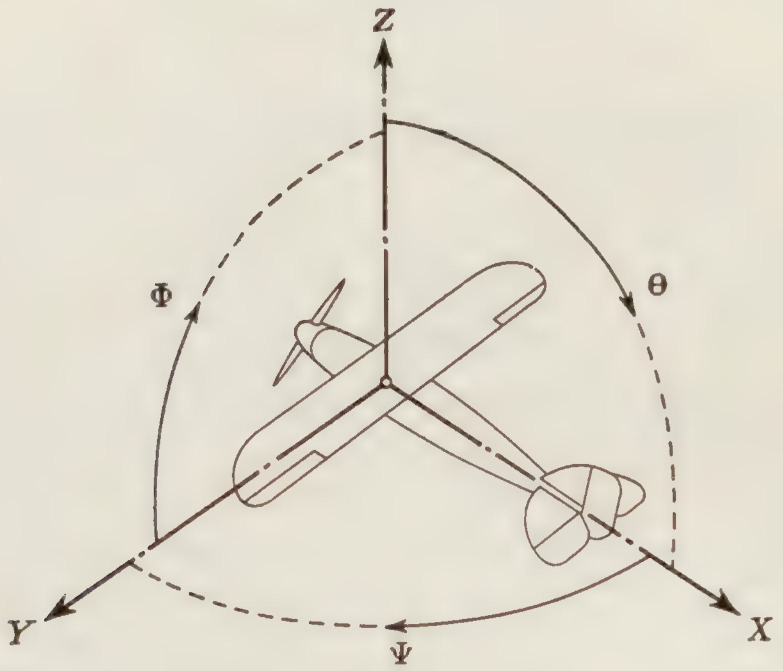
or for a model of 10 cm chord 40 m/sec, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of *C. P.* from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $= (i_t - i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.



Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L=\frac{L}{qbS}\quad C_M=\frac{M}{qcS}\quad C_N=\frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.

(If "coefficients" are introduced all units used must be consistent.)

η, Efficiency $= T\,V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute., R. P. M.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 HP = 76.04 kg/m/sec. = 550 lb./ft./sec.
1 kg/m/sec. = 0.01315 HP.
1 mi./hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.

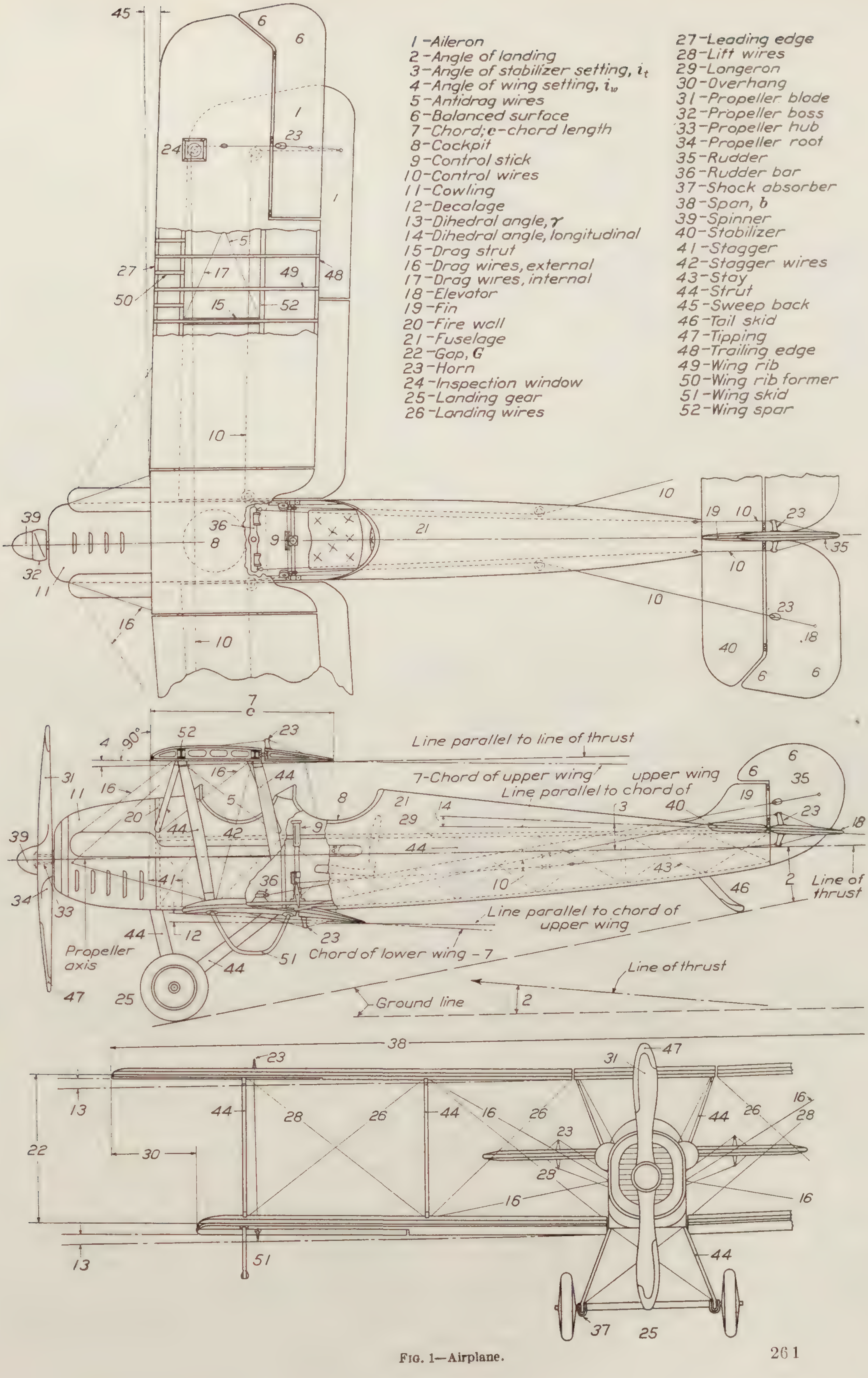
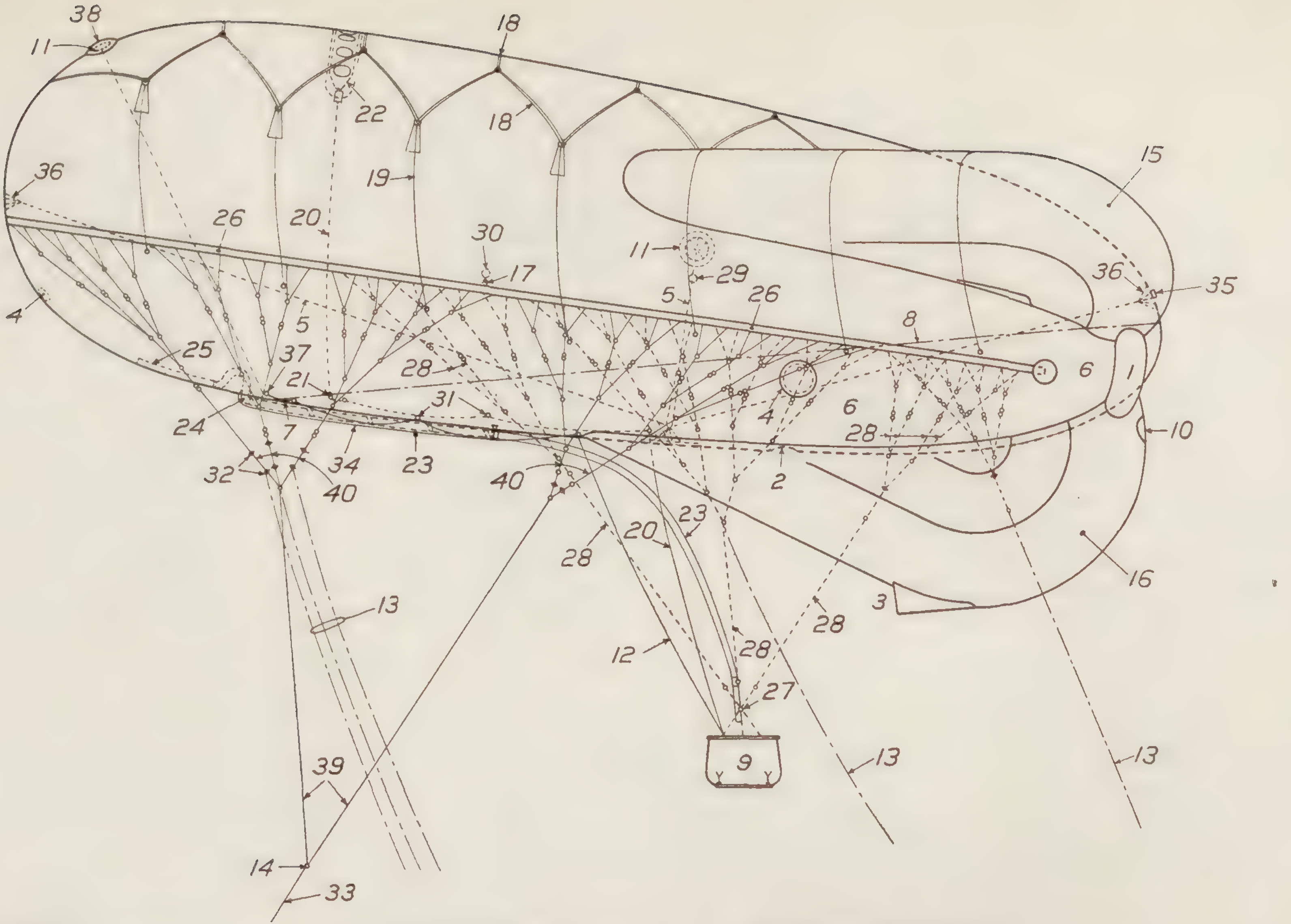
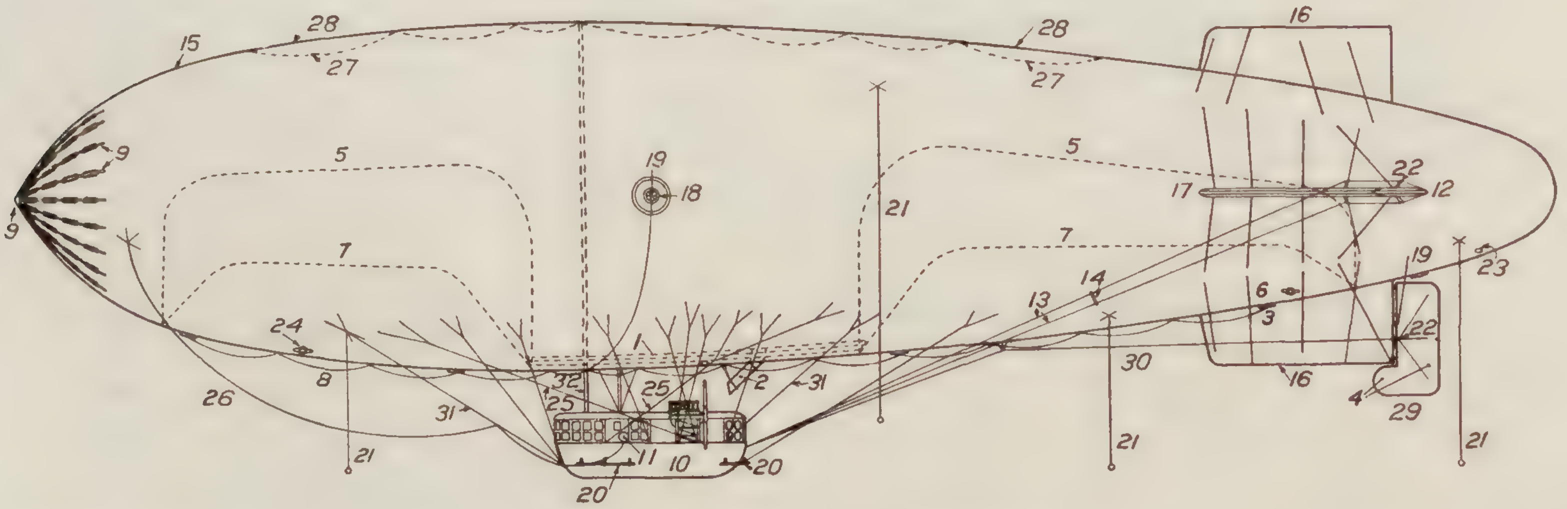


Fig. 1—Airplane.



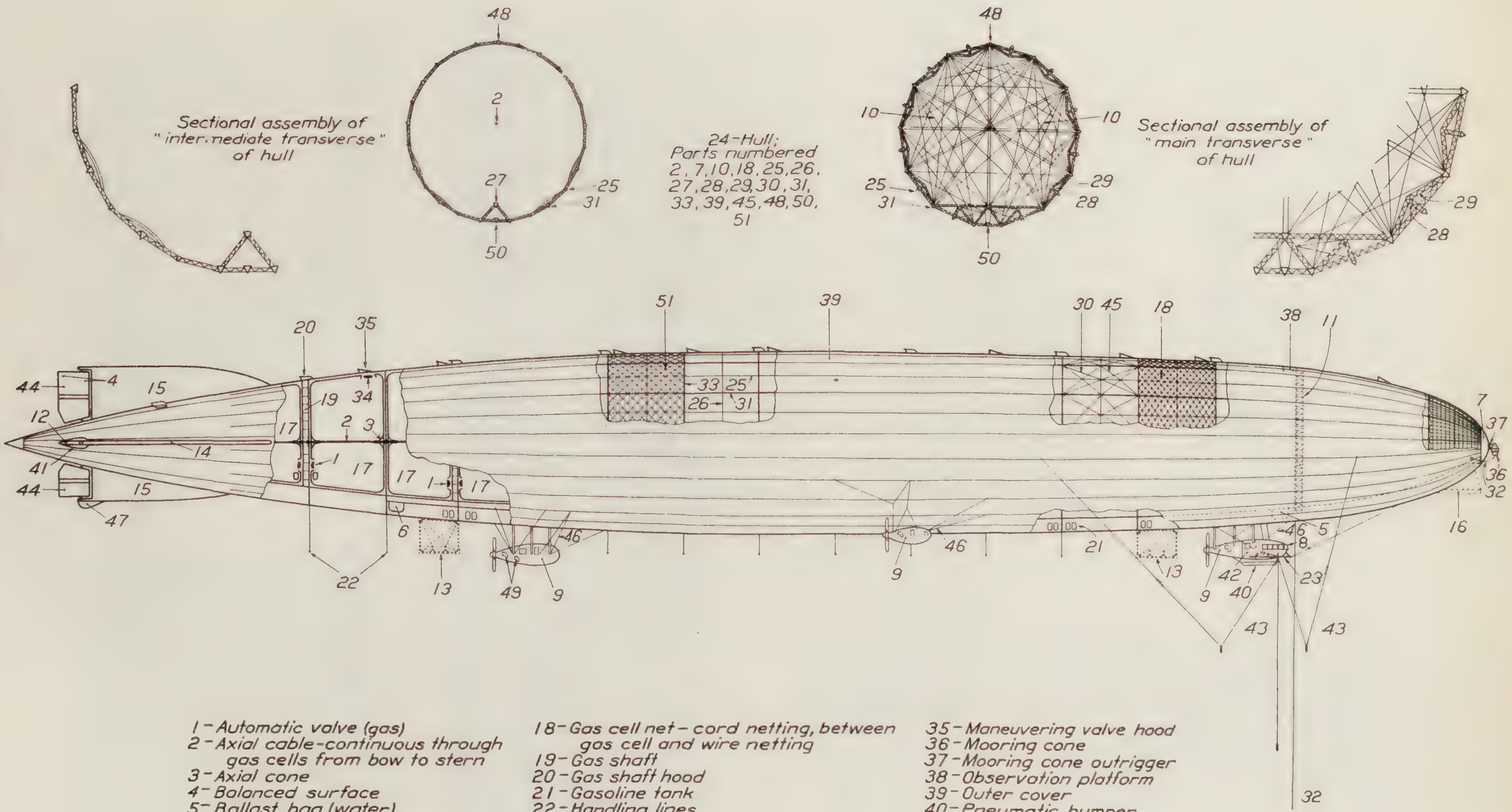
1-Air duct
2-Air opening into ballonet
3-Air scoop
4-Appendix manhole
5-Automatic valve rigging
6-Ballonet
7-Ballonet deflation hole
8-Ballonet diaphragm seam
9-Basket
10-Deflation sleeve
11-Gas valve
12-Hand valve line
13-Handling lines
14-Junction piece
15-Lobe, lateral; stabilizer
16-Lobe, vertical; stabilizer
17-Manometer tube attachment
18-Mooring bands
19-Mooring ropes
20-Rip cord
21-Rip cord gland
22-Rip panel
23-Supply tube
24-Supply tube check valve
25-Supply tube discharge tube
26-Suspension band
27-Suspension bar
28-Suspension lines
29-Tie patch for manometer tube
30-Tie patch for rip cord and valve line
31-Tie patch for internal valve line
32-Toggle
33-Towing or traction cable
34-Tube cover
35-Valve adjusting gland
36-Valve cord attachment pyramid
37-Valve gland
38-Valve hood
39-"V" wires (steel)
40-Winch suspension

Fig. 2.—Kite balloon



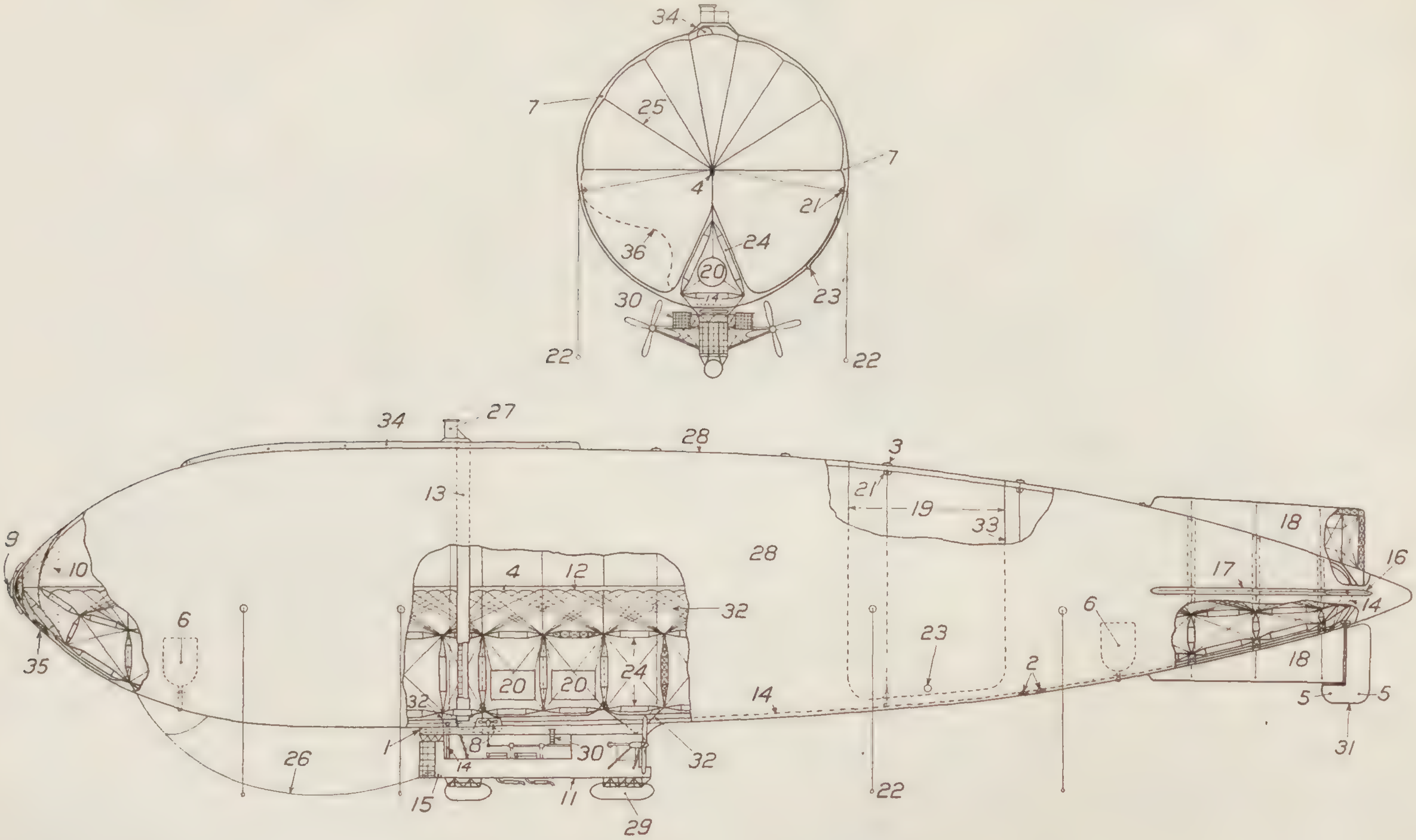
1-Air pipe to ballonet
2-Air scoop
3-Air valve
4-Balanced surface
5-Ballonet
6-Ballonet manhole
7-Ballonet seam
8-Ballonet valve cord
9-Bow cap and stiffeners
10-Car
11-Drag rope stowage
12-Elevator (balanced)
13-Elevator control lines
14-Elevator control line fairlead
15-Envelope
16-Fin, vertical
17-Fin, horizontal
18-Gas manhole
19-Gas valve
20-Hand rail
21-Handling lines
22-Horn (rudder, elevator)
23-Inflation sleeve
24-Inspection window
25-Martingales
26-Mooring line
27-Rip cord
28-Rip panel
29-Rudder (balanced)
30-Rudder control lines
31-Suspension line, car
32-Valve operating lines

Fig. 3.—Nonrigid airship



1 - Automatic valve (gas)
2 - Axial cable-continuous through gas cells from bow to stern
3 - Axial cone
4 - Balanced surface
5 - Ballast bag (water)
6 - Ballast bag (water) emergency
7 - Bow cap
8 - Car, control
9 - Car, power
10 - Chord wires
11 - Climbing shaft
12 - Elevator (balanced)
13 - Field handling frame
14 - Fin, horizontal
15 - Fin, vertical
16 - Gangplank
17 - Gas cell
18 - Gas cell net - cord netting, between gas cell and wire netting
19 - Gas shaft
20 - Gas shaft hood
21 - Gasoline tank
22 - Handling lines
23 - Hand rail
24 - Hull
25 - Intermediate longitudinal
26 - Intermediate transverse
27 - Keel apex girder
28 - King post
29 - King post brace
30 - Main diagonal wiring
31 - Main longitudinal
32 - Main mooring line
33 - Main transverse
34 - Maneuvering valve (gas)
35 - Maneuvering valve hood
36 - Mooring cone
37 - Mooring cone outrigger
38 - Observation platform
39 - Outer cover
40 - Pneumatic bumper
41 - Quadrant
42 - Radio room
43 - Radio antenna
44 - Rudder (balanced)
45 - Secondary diagonal wiring
46 - Suspension line, car
47 - Skid
48 - Top center-line girder
49 - Ventilators
50 - Walk-way girder
51 - Wire netting - between cord netting and metallic framework

FIG. 4.—Rigid airship



1-Air duct
2-Air valve
3-Automatic and manual valve (gas)
4-Axial suspension band
5-Balanced surface
6-Ballast (water)
7-Ballonet
8-Ballonet blower
9-Bow cap
10-Bow stiffeners
11-Car (control and power)
12-Catenary
13-Climbing shaft
14-Control cables
15-Drag rope (stowage)
16-Elevator (balanced)
17-Fin (horizontal)
18-Fin (vertical)
19-Gas container
20-Gasoline tank
21-Gland
22-Handling lines
23-Inflation sleeve
24-Keel, continuous from bow to stern (articulated)
25-Longitudinal diaphragm
26-Mooring line
27-Observation platform
28-Outer cover
29-Pneumatic bumper
30-Radiator
31-Rudder (balanced)
32-Suspension wires
33-Transverse diaphragm
34-Valve hood
35-Ventilator
36-Wall of gas cell under partial deflation

FIG. 5—Semirigid airship

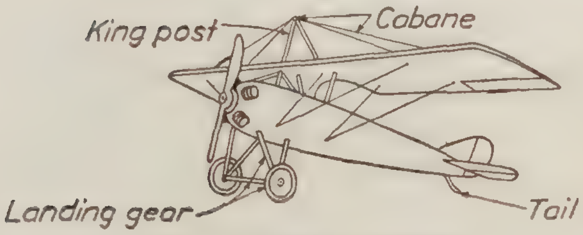


FIG. 6.—Tractor monoplane

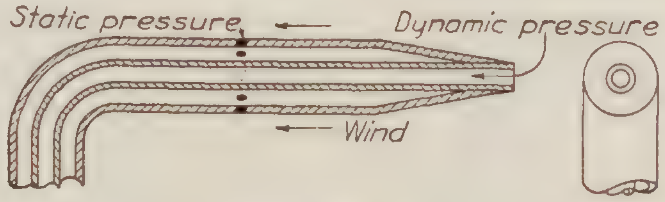


FIG. 7.—Pitot tube

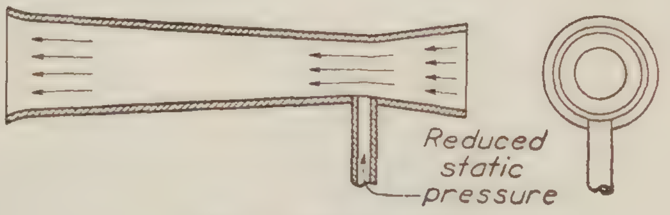


FIG. 8.—Venturi tube

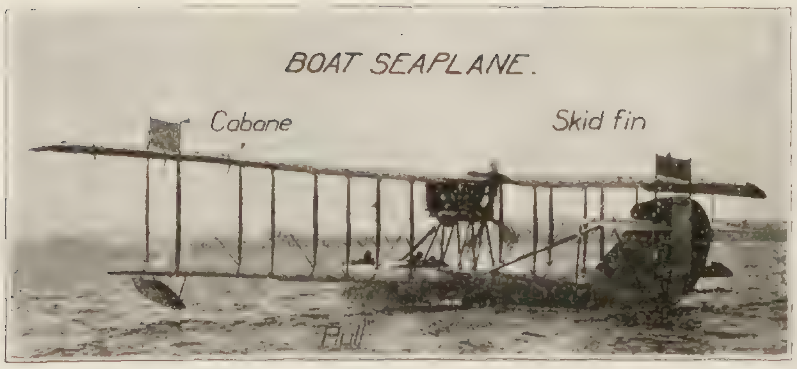


FIG. 9.—Boat seaplane

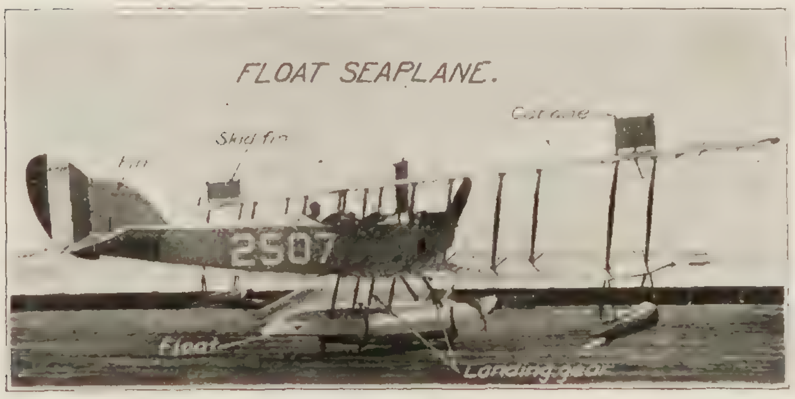


FIG. 10.—Float seaplane

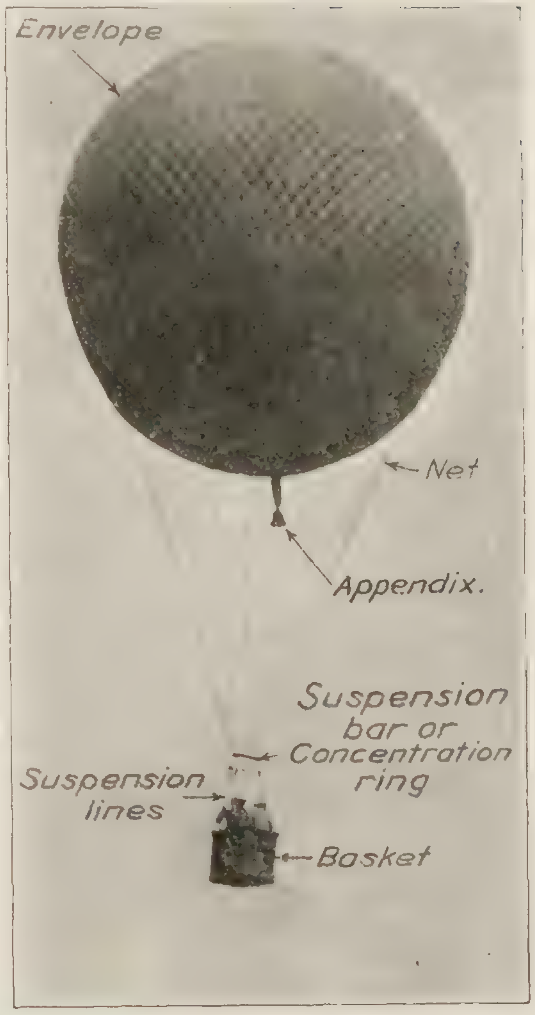


FIG. 11.—Free balloon

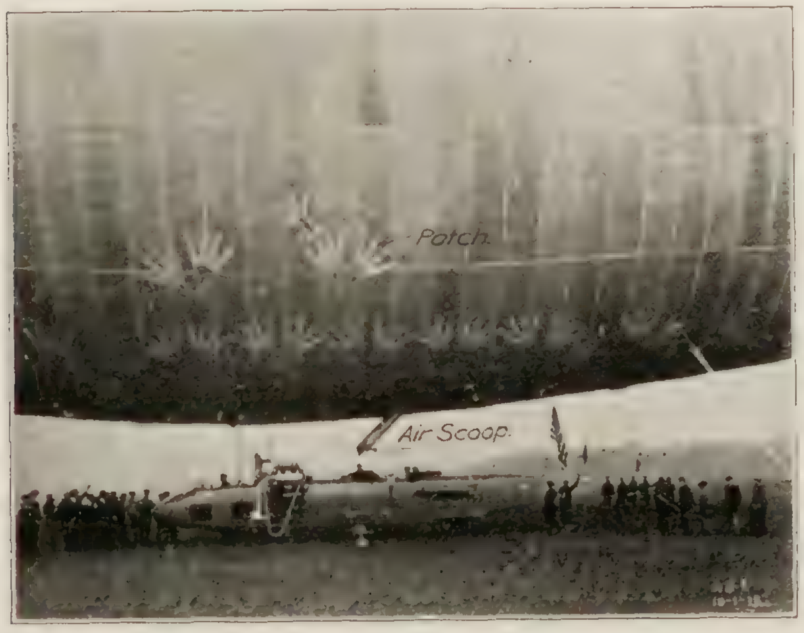


FIG. 12.—Air scoop and patch

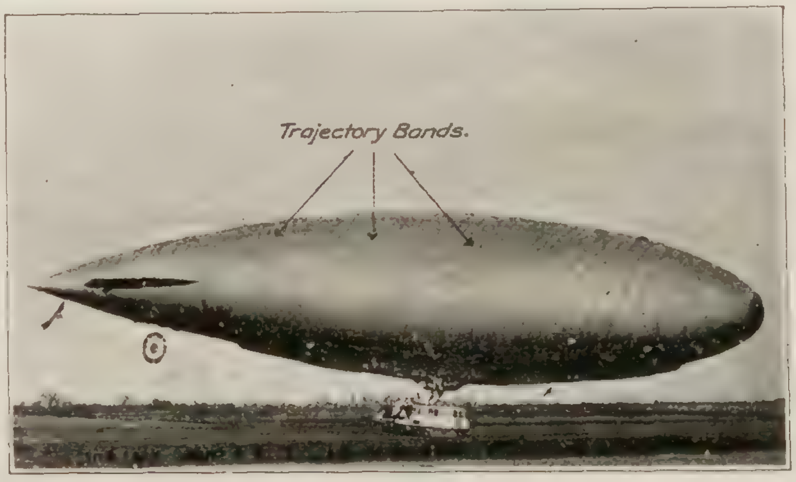


FIG. 13.—Trajectory bands

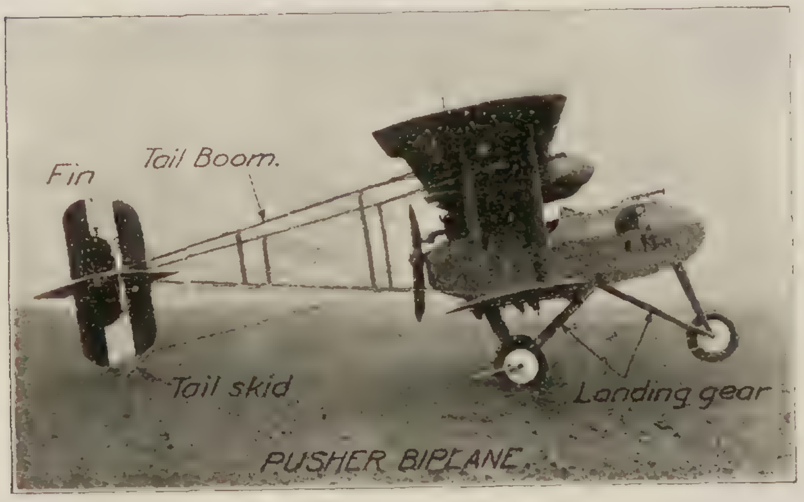


FIG. 14.—Pusher biplane

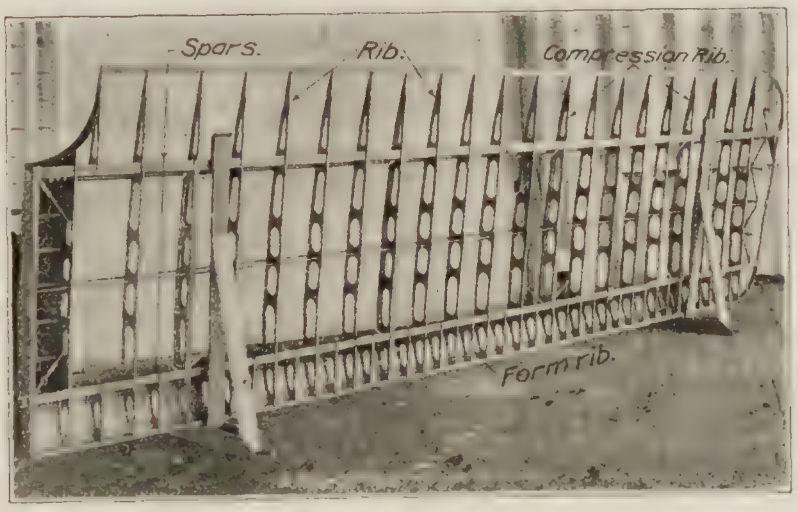


FIG. 15.—Skeleton of wing

REPORT No. 241

ELECTRICAL CHARACTERISTICS OF SPARK GENERATORS FOR AUTOMOTIVE IGNITION

By R. B. BRODE, D. W. RANDOLPH, and F. B. SILSBEE
Bureau of Standards

REPORT No. 241

ELECTRICAL CHARACTERISTICS OF SPARK GENERATORS[1] FOR AUTOMOTIVE IGNITION

By R. B. Brode, D. W. Randolph, and F. B. Silsbee

SUMMARY

This paper reports the results of an extensive program of measurements on 11 ignition systems differing widely in type. The results serve primarily to give representative data on the electric and magnetic constants of such systems, and on the secondary voltage produced by them under various conditions of speed, timing, shunting resistance, etc. They also serve to confirm certain of the theoretical formulas which have been proposed to connect the performance of such systems with their electrical constants, and to indicate the extent to which certain simplified model circuits duplicate the performance of the actual apparatus.

INTRODUCTION

For several years the Bureau of Standards has carried on a study of ignition systems for the National Advisory Committee for Aeronautics and other branches of the Federal Government. Much of this work has been devoted to the solution of special problems of immediate urgency, but throughout the work the need has been felt for the formulation of a systematic basic theory of operation of such apparatus, and whenever opportunity permitted the work has been directed toward the foundation of such a theory. National Advisory Committee for Aeronautics reports No. 58, "Characteristics of High Tension Magnetos," and No. 123, "Simplified Theory of the Magneto," together with Bureau of Standards Scientific Paper No. 424, "Mathematical Theory of Induced Voltage in the High Tension Magneto," constitute steps in this work. In 1922 a program of measurements was undertaken on a group of spark generators for the purpose of determining (1) their performance under various conditions of operation, (2) the electrical and magnetic characteristics of the apparatus, and (3) the extent to which the theoretical relations set forth in the reports listed above could be applied to these particular types of spark generators. The principal results of this investigation are here presented.

The ignition systems used in this work were all of the jump-spark type, and included both battery-coil and magneto systems. The systems were selected so as to give as great a variety as possible in the arrangement of the magnetic circuit. A detailed description of the systems will be found in the section under "Description of the spark generators studied," of this report. In considering the results of this work it should be borne in mind that the tests given cover only the electrical performance and not the mechanical quality of the apparatus, and furthermore that the data were all obtained with apparatus which was new and in good condition. In finally judging the relative merits of different types of spark generators such features as mechanical workmanship, resistance to wear, waterproofness, and other qualities which could be demonstrated only by protracted endurance tests are of great importance. These factors, however, have not been dealt with in the present paper. It should also be mentioned that, in order to cover apparatus differing as much as possible in the type of magnetic circuit, machines have been included which differ greatly in size and cost, and which would not normally enter into competition with one another in any single application. Still another point that should be mentioned is that some of the magnetos give four sparks per revolution, while others give only two sparks per revolution. Magnetos of the former class are, in general, used with engines having a large number of cylinders, while the latter are used on engines of a smaller number of cylinders where the magneto is not necessarily required to operate at such high speeds relative to the engine crankshaft. This fact should be taken into account when making comparisons, as, for example, in the case of the curves showing crest voltage at slow operating speeds.

---

[1] Following British practice the term "spark generator" is here used to designate the electrical equipment which directly serves to produce the ignition spark; and includes both the high-tension magneto and the battery, induction coil, and breaker of a battery-coil system.

SPARK-GENERATOR REQUIREMENTS

The requirements for the satisfactory operation of a spark generator are as follows:

(*a*) It must produce sufficient voltage to break down the gap at the spark plug.
(*b*) Each spark must be capable of igniting an explosive mixture.
(*c*) The sparks must occur at the proper time in the engine cycle.

These requirements must be met under the following conditions:

1. At any speed within the normal range of engine operation.
2. While the system is shunted by the capacitance of the spark plug and connecting wires.
3. While the system is shunted by the conductance of the layer of carbon which may be deposited on the insulation of the spark plug.

Paterson and Campbell (Reference 1) have shown by experiments on gasoline-air mixtures that ignition will be produced provided the energy in the spark is not less than 0.00025 joule. The limiting energy depends considerably upon the sparking voltage of the gap, but it is found that if the capacitance has the smallest value which is likely to be met with in automotive equipment, and if the sparking voltage has the lowest value which is likely to occur with a spark plug of normal construction, the energy in the spark is considerably greater than the minimum necessary to produce ignition. Experiments at the Bureau of Standards (Reference 2) have shown that even if the spark energy greatly exceeds this minimum value the rate of flame spread in gaseous mixtures and hence the power of the engine are unaffected. We may therefore conclude that intensity of the spark is not a measure of the effectiveness of the ignition system, and that, in general, satisfactory ignition will take place during engine operation if a spark is produced at all.

Upton (Reference 3) states that a departure of ±15° from the best position in the timing of the spark may produce a change of 10 per cent in engine power, but that the change in power will not exceed 1 per cent provided the spark timing does not vary more than ±4° from the optimum position. This degree of accuracy in timing is easily obtainable by a direct drive from the engine shaft to the breaker cam which determines the spark timing. It is easily possible to obtain any reasonable amount of advance and retard range on battery systems and on certain types of magnetos by shifting the position of the breaker cam or of the cam follower relative to the drive shaft. In most types of magneto, however, the cam or its follower is shifted with respect to the magnetic field also, and the requirements of the timing range constitute an important limitation on the design.

The engine speed fixes the number of sparks which the spark generator is called upon to produce per minute, and thus limits the time interval between sparks during which the energy for the succeeding spark can be stored. At high speeds this limitation of time tends to reduce the effectiveness of the spark generator either by reducing the value of current which is obtained at the instant of break, as in the case of battery systems, or by requiring in the magneto the use of a magnetic circuit giving a large number of flux reversals per revolution, and hence having available only a relatively small cross section of air gap to carry the magnetic flux. On the other hand, battery systems are able to work with full effectiveness at slow speeds while the voltage output from a magneto drops off to zero at zero speed. In certain types of magneto this difficulty is avoided by the use of impulse starters or by the device of connecting a battery in series with the magneto primary.

A spark will be produced at the spark plug only if the voltage impulse furnished by the spark generator exceeds the breakdown voltage of the gap. This breakdown voltage is affected by a large number of variables, such as the length of the gap, the shape of the electrodes, the density of the gas mixture in the spark-plug gap, the presence of an oil film on the surface of the electrode, the temperature of the electrodes, etc. (Reference 4.)

In general, the breakdown voltage of the spark-plug gap is seldom less than 2,000 volts and seldom greater than 8,000 volts under most automotive conditions.

The leads connecting the spark generator to the spark plugs have a certain amount of capacitance, which is, of course, larger if these leads are run in a grounded metal conduit. In general, however, the capacitance of the leads is small compared with the capacitance which is inherent in the windings and the condenser of the spark generator itself; therefore the effect of such external capacitance upon the operation of the spark generator is of little importance. Nevertheless, since such capacitance is always present in the use of the spark generator, a knowledge of its effect is often desirable in order to make sure that the spark generator is not unduly sensitive to the presence of such a burden.

Since a portion of the insulator of the spark plug is liable to become covered with a conducting layer of carbon, it is very important that a spark generator be able to produce a spark even when shunted by such a conducting path. The value of the conductance (reciprocal of the shunting resistance) at which the spark generator will just fire a spark gap of standard voltage is termed by British writers the "utility" of the generator, and by some is considered as the most important property of a spark generator. In extreme cases when an exceedingly hot engine is operated with spark-plug insulators of poor quality, there may be enough conductance through the body of the insulator to affect the operation of the spark generator. In most cases, however, the conductance arises only from deposits of carbon.

From the above discussion it appears that in consideration of the electrical performance of the spark generator attention should be focused primarily on the question of whether or not it will produce the necessary sparking voltage over the needed range of conditions of shunting resistance and engine speed.

Data of this type on the various generators tested are given in section under "Experimental data."

DESCRIPTION OF THE SPARK GENERATORS STUDIED

The spark generators used in this program of measurements were selected primarily to secure as wide a variety as possible in the arrangement of the magnetic circuit. Magneto E, of foreign manufacture, was received by the bureau in 1917. Magneto K was an experimental machine submitted for test in 1917. The other systems were kindly loaned by their respective makers for the purposes of this test in 1922 and may be considered as representing the types on the market at that time.

Tables 1 and 2 give general descriptive data on these spark generators which were all of the "single-spark" type.

Magnetos A and B are supplied with jump-spark distributors, but the measurements were all made with a direct connection to the high-tension terminal.

Magneto A is of the inductor type. Both the magnet and the coils on their laminated core are stationary. The axis of the core on which the coils are wound is perpendicular to the axis of the magnetic pole pieces and to the axis of the rotor. The poles of the magnet and extensions of the core form alternate sections of magnetic material each subtending nearly 90° around the periphery of the rotor tunnel. The rotor carries two segments of laminated iron embedded in a cylindrical die casting. As the rotor revolves these segments provide a flux path of low reluctance between the magnet poles and the adjacent extension of the coil core and cause the flux through the latter to reverse its direction four times for each revolution of the rotor.

Magneto B is similar to magneto A, but its magnets have about twice the volume, and it is provided with interchangeable cams and distributors for use on either a 6-cylinder or a 12-cylinder engine.

Magneto C is of the conventional "H-armature" or shuttle type. The coils, condenser, and contact points rotate with the core and the contacts are operated by a fixed annular cam.

Magneto D has a "U-shaped magnet, mounted to rotate about its axis of symmetry and fitted with laminated pole tips. The coils are mounted on a laminated stationary core placed above the magnet and with its axis at right angles to the axis of rotation.

Magneto E is of the sleeve type. The magneto and pole pieces are similar to those of conventional H-armature type. The armature core is also of the conventional shape but is held stationary in the center of the tunnel with its magnetic axis at right angles to the magnetic axis of the magnets. In the wide air gap between the poles and the armature there revolves a hollow cylindrical sleeve. Two 90° sectors of this sleeve are of iron while the alternate sectors are non-magnetic. As the sleeve rotates through a complete revolution the flux through the armature core reverses four times. The flux through the core has a maximum value when the magnetic sectors of the sleeve overlap a pole piece on one side and the core on the other by 45°. The four positions in which this condition holds are all symmetrical and hence the maximum flux values are all equal. The positions of zero core flux, however, do not all correspond to equal geometric arrangements. In two positions the magnetic sectors are under the magnetic poles and bridge the tips of the armature; while in the other two positions the magnetic sectors lie outside the end of the core and bridge across the pole tips of the magnet. Because of this condition the alternate-current waves generated by this magneto are not quite alike, and the values of current at break as shown in Figure 35 are unequal. Since the performance data was obtained by a crest voltmeter, it corresponds to the half waves which give the greater secondary voltage (i. e., wave A at low speeds and wave B at high speeds).

Magneto F is also of the inductor type, but differs from A and E in that the axis of the stationary core is parallel to the rotor axis and lies above it. The axis of the permanent magnets is horizontal and perpendicular to the axis of rotation. The rotor tunnel is surrounded by a die casting which contains four embedded sections of laminated iron. Two of these sections lie slightly above the ends of a horizontal diameter of the tunnel and extend along its entire length. These sections form the pole faces of the magnet. The other two sections lie at the top of the casting and each is somewhat less than half as long as the rotor. These two sections form the terminal extensions of the core on which the coil is wound. Each of the sections subtends an angle of about 45°.

The rotor consists of a cylindrical die casting in which are embedded four segments of laminated iron arranged in two pairs, one at either end of the rotor. Each segment is of the same length as the smaller fixed sections which form the core terminals (i. e., somewhat less than half the rotor length), and subtends an angle of 135° on the rotor circumference. The axis of one pair of segments is at right angles to the axis of the other pair. Each revolution of the rotor causes the flux through the core to reverse its direction four times. The cam, however, is provided with only two lobes so that only half of the possible sparks are made use of in the machine as operated. The breaker points are held open by the cam during the two quarter revolutions not used.

Magneto G is provided with an L-shaped magnet which permanently polarizes two large pole pieces. Extending from one pole piece are two cores, on one of which the coils are wound while the other or dummy core is bare. The rotation of the two-lobed rotor serves to direct the flux through one or the other of the two cores in alternation, thus providing four rather abrupt changes in the magnitude of the flux through the core for each revolution, although the flux does not reverse its direction at all. Like magneto F, however, magneto G is provided with a two-lobed cam, and thus makes use of only half the possible number of sparks.

The coils H, I, and J are wound on cores of iron wire. Coil H is of the usual open core type, having a ratio of length to diameter of 5.6: 1. I and J, however, have the external magnetic circuit closed by a yoke of iron wire so that the air gap in the magnetic circuit is only about 2 mm. long. Coils H and I are designed for use with a 6-volt battery, while coil J is designed for 12 volts.

Magneto K is of the conventional H-armature type, but has large openings cut in the solid pole pieces in order to reduce the eddy currents.

EXPERIMENTAL DATA

The following pages give in condensed form the experimental data obtained on the performance characteristics of these ignition systems.

The principal data consist of the values of maximum (or crest) secondary voltage observed with the system operating under various conditions. Figures 1 to 8 show, for the magneto system, the variation of this voltage with speed with no shunting resistance in parallel with the terminals. It will be noted that this voltage increases rapidly with speed until a value indicated by "G" is reached at which sparking occurs at the safety gap. Readings obtained at higher speeds would, of course, correspond merely to the sparking voltage of this gap and have no bearing on the functioning of the other parts of the machine. The crest voltmeter used in these measurements consisted of an electrostatic voltmeter in series with a kenetron and acted as only a very small capacitance load on the secondary terminals. (Reference 5.) When two curves are shown, one corresponds to the fully advanced and the other to the fully retarded position of the breaker mechanism.

Figures 9 to 19 show the effect of shunting resistance upon secondary voltage at full advance and at two different speeds. In the case of the magnetos the higher speed was such as to give 2,000 sparks per minute and the lower was 50 revolutions per minute. In the battery systems the speeds gave 5,000 and 800 sparks per minute, respectively. In each figure one or two curves were obtained with only the unavoidable additional capacitance caused by the leads and voltmeter. This minimum value was about 75 $\mu\mu$f. An additional curve was obtained when a condenser of about 240 $\mu\mu$f capacitance was also connected between the secondary terminal and ground and the machine was operating at the higher speed.

The effect of capacitance is also shown in Figures 20 to 30. In these figures the curve shows the crest voltage plotted against capacitance for a speed corresponding to 2,000 sparks per minute and for a wide range of capacitance. The straight line shows the reciprocal of the square of the secondary crest voltage $\left(\frac{1}{V_m^2}\right)$ plotted against the same abscissae. The significance of the fact that this latter plot gives a nearly straight line will be discussed below.

In producing the results given above each magneto performs two fairly distinct operations: first, as a generator it produces a primary current; and second, as an induction coil it develops a high voltage when that current is suddenly interrupted. The first step in analyzing the performance, therefore, is to determine the value of the primary current flowing in each case at the instant of break, and thus separate the two parts of the operation. This was done by taking a number of oscillograms at various operating speeds. The results of such measurements are shown in Figures 31 to 39. In these measurements the oscillograph vibrator was connected in parallel with a low-resistance shunt, which in turn was inserted in series with the primary circuit. The resistance of the shunt was kept as small as possible and in most cases was about 0.07 ohm. The effect of this resistance is entirely negligible at the higher magneto speeds where the current is limited by inductance but may have caused a decrease of nearly 10 per cent in the current values at the lowest speed.

In the machines having adjustable spark timing, records were taken both at full advance and at full retard. The corresponding curves are drawn in solid lines in the figures and show the value of current at the instant the contact points begin to separate. In some cases the break at "advance" occurs before the current has reached its maximum value and the break at "retard" occurs after the current has decreased materially from its maximum value. The dotted curve marked "max" in Figures 31 and 37, shows this maximum value of current reached while the magneto was operating with the cam in the "retard" position. The maximum performance which can be obtained from a given magneto, of course, occurs with the breaker in an intermediate position, and this dotted curve enables one to estimate this performance by increasing the observed values of voltage previously given, in proportion to this increase in primary current.

In the case of system E alternate half waves are of different wave form. Two curves are therefore given in Figure 35, although this machine has fixed spark timing.

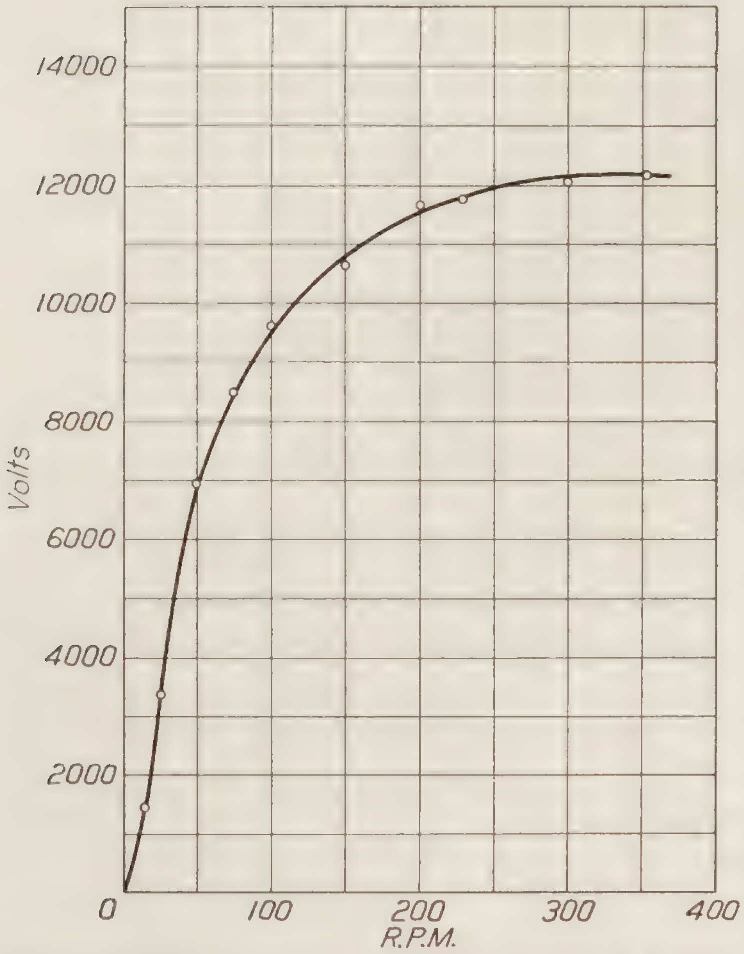


FIG. 1.—Secondary crest voltage vs. speed for magneto A (inductor type), fixed timing, 4 sparks per revolution

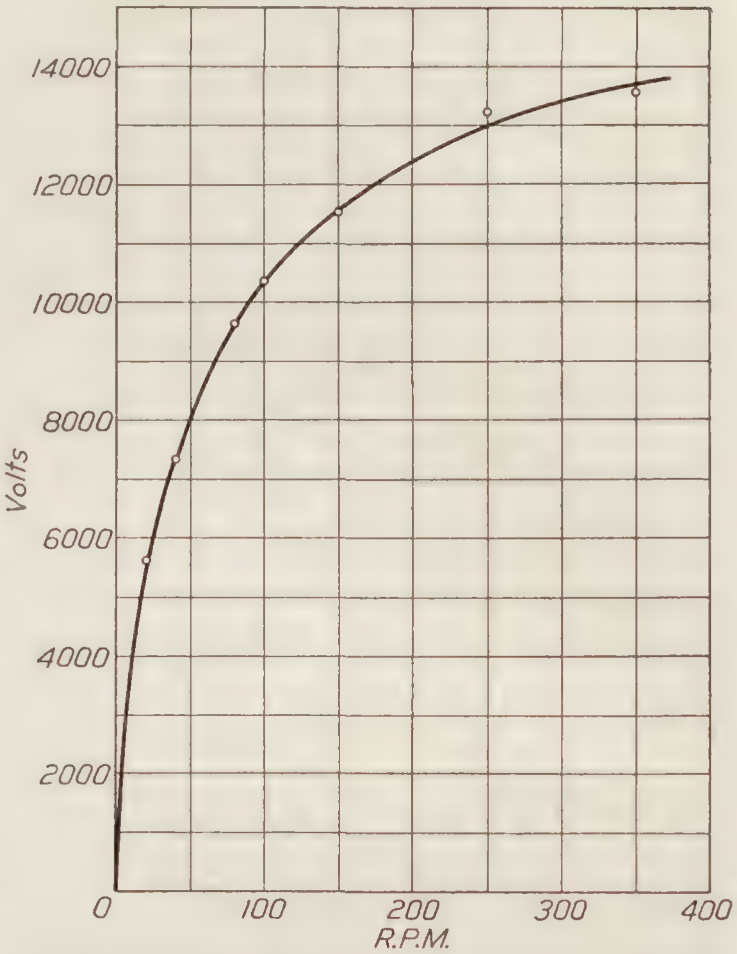


FIG. 2.—Secondary crest voltage vs. speed for magneto B (inductor type), full advance, 4 sparks per revolution

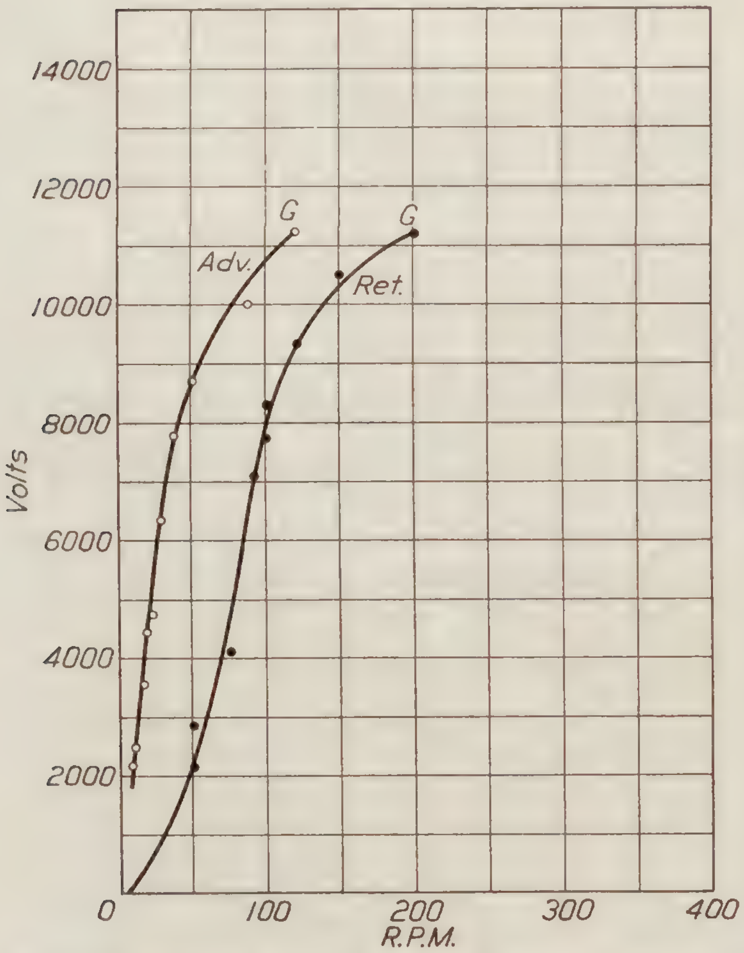


FIG. 3.—Secondary crest voltage vs. speed for magneto C (shuttle-core type) at full advance and at full retard; G indicates firing of safety gap, 2 sparks per revolution

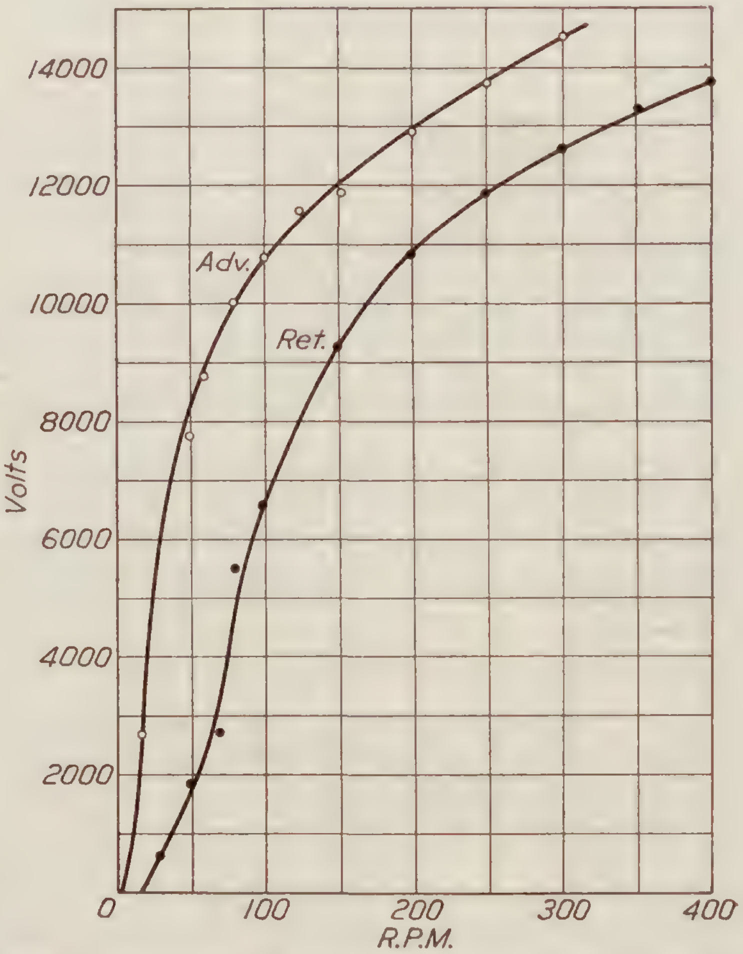


FIG. 4.—Secondary crest voltage vs. speed for magneto D (revolving-magnet type) at full advance and at full retard, 2 sparks per revolution

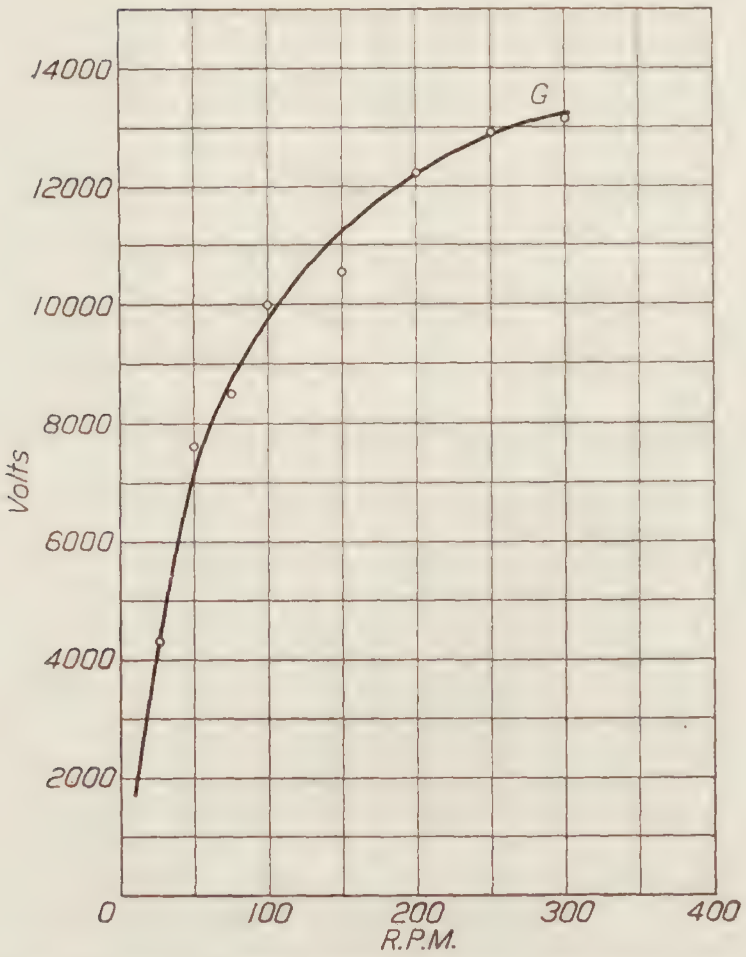


FIG. 5.— Secondary crest voltage vs. speed for magneto E (sleeve-inductor type), fixed timing; G indicates firing of safety gap, 4 sparks per revolution

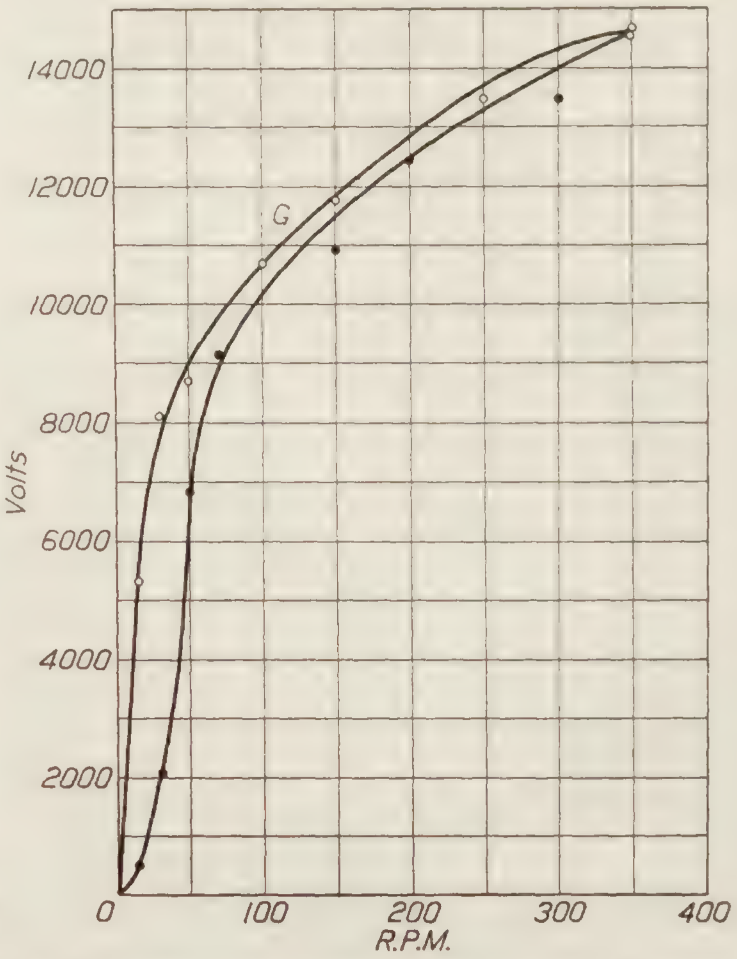


FIG. 6.—Secondary crest voltage vs. speed for magneto F (inductor type) at full advance and at full retard; G indicates occasional firing in safety gap, 2 sparks per revolution

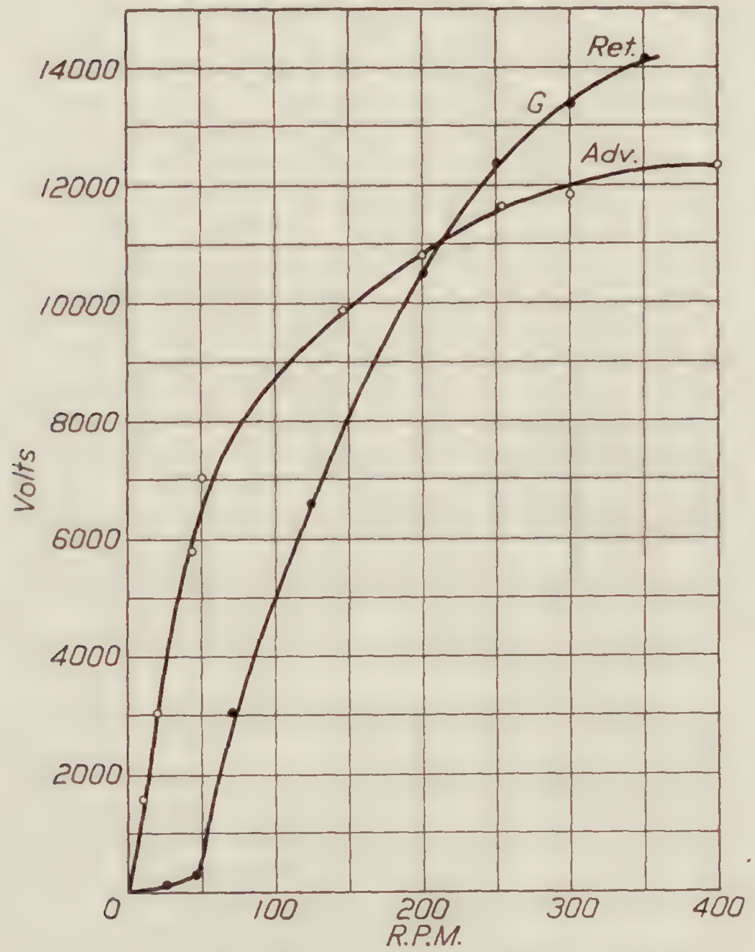


FIG. 7.—Secondary crest voltage vs. speed for magneto G (pulsating-flux type) at full advance and at full retard; G indicates firing at safety gap, 2 sparks per revolution

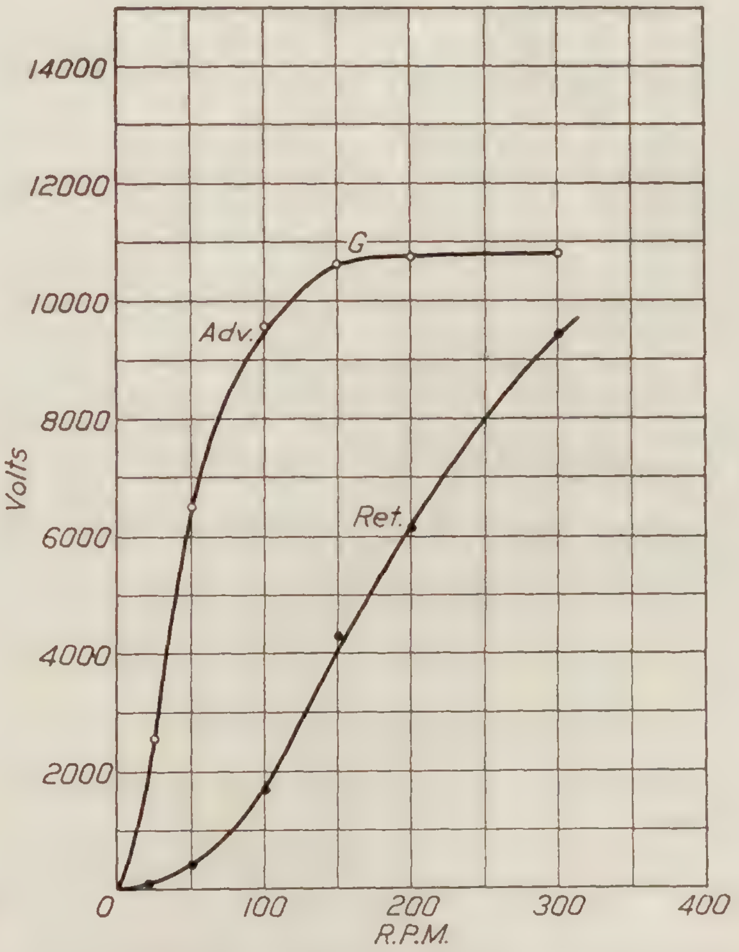


FIG. 8.—Secondary crest voltage vs. speed for magneto K (shuttle-core type) at full advance and at full retard; G indicates firing at safety gap, 2 sparks per revolution

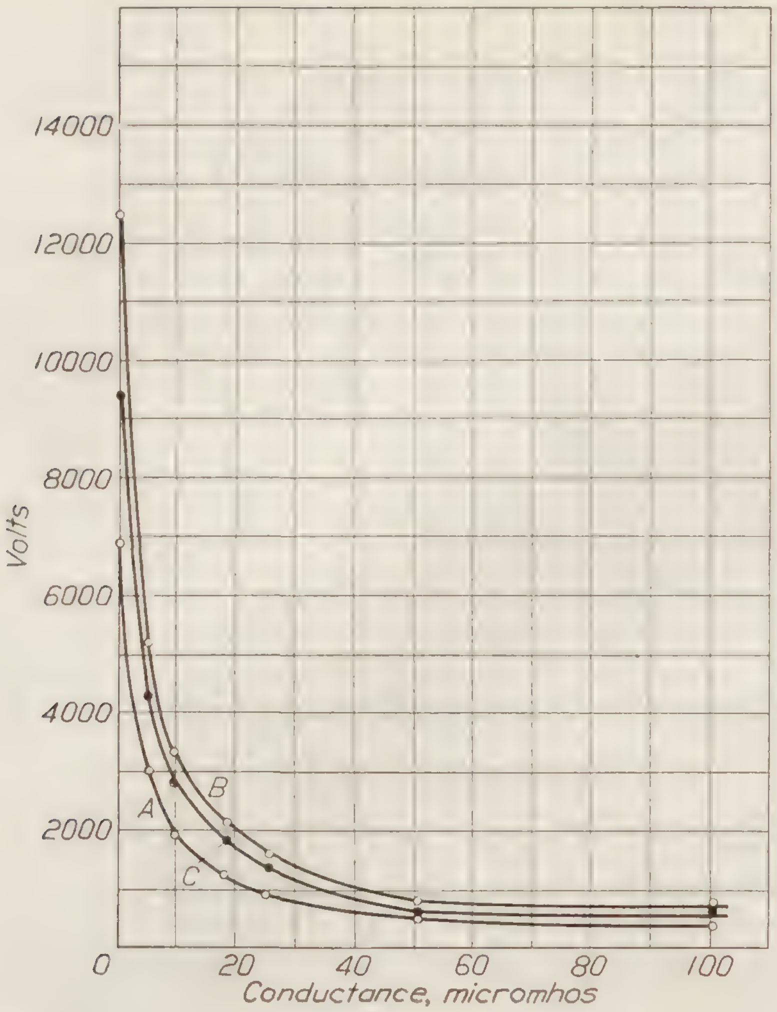


FIG. 9.—Secondary crest voltage vs. shunting conductance for magneto A (inductor type); **A** at 50 R. P. M., **B** at 500 R. P. M., **C** same as **B** but with an additional condenser of 250 $\mu\mu$f capacitance shunting the secondary

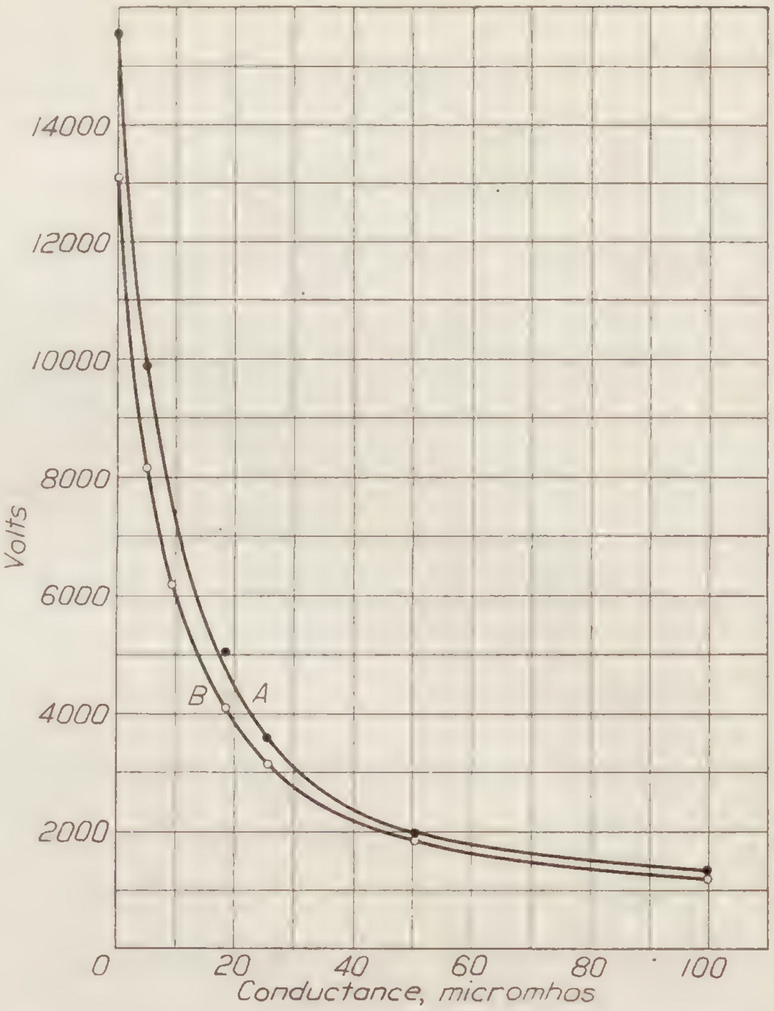


FIG. 10.—Secondary crest voltage vs. shunting conductance for magneto B (inductor type) at full advance; **A** at 500 R. P. M., **B** same as **A** but with an additional condenser of 260 $\mu\mu$f capacitance shunting the secondary

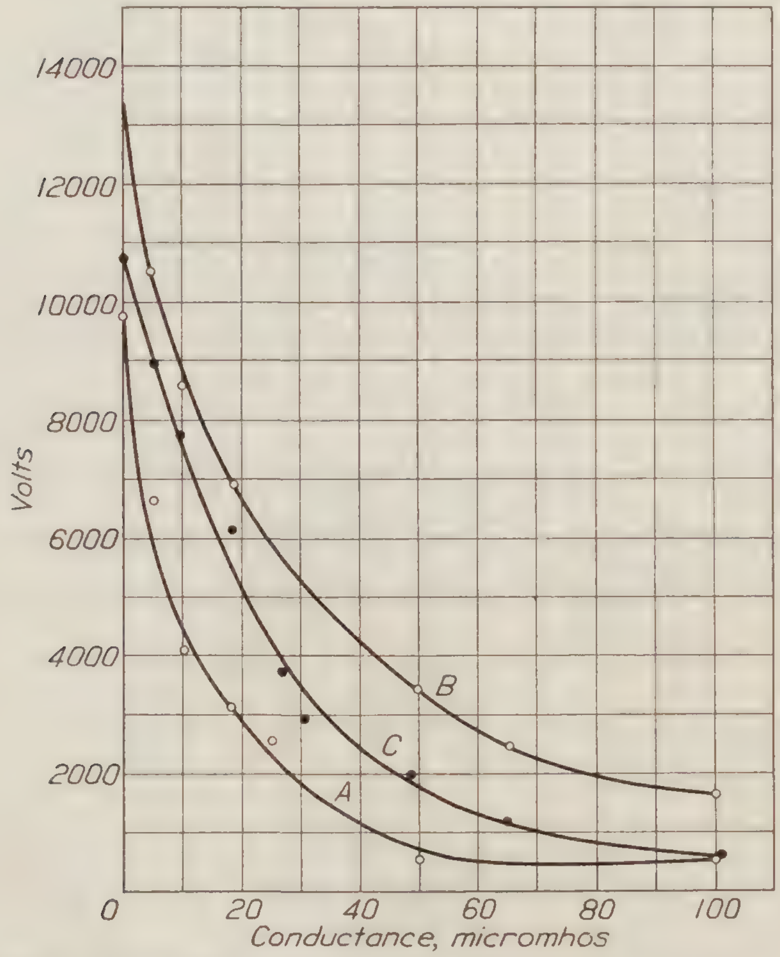


FIG. 11.—Secondary crest voltage vs. shunting conductance for magneto C (shuttle-core type) at full advance; **A** at 50 R. P. M., **B** at 1,000 R. P. M., **C** same as **B** but with additional condenser of 230 $\mu\mu$f capacitance shunting the secondary

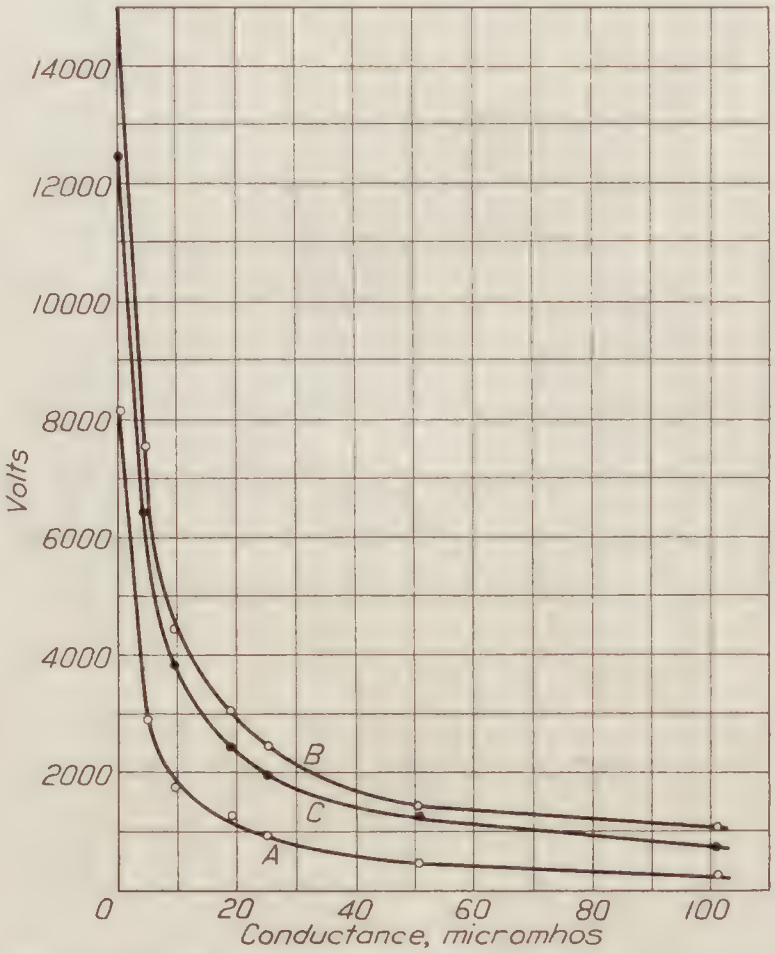


FIG. 12.—Secondary crest voltage vs. shunting conductance for magneto D (revolving-magnet type); **A** at 50 R. P. M., **B** at 1,000 R. P. M., **C** same as **B** but with an additional condenser of 280 $\mu\mu$ capacitance shunting the secondary

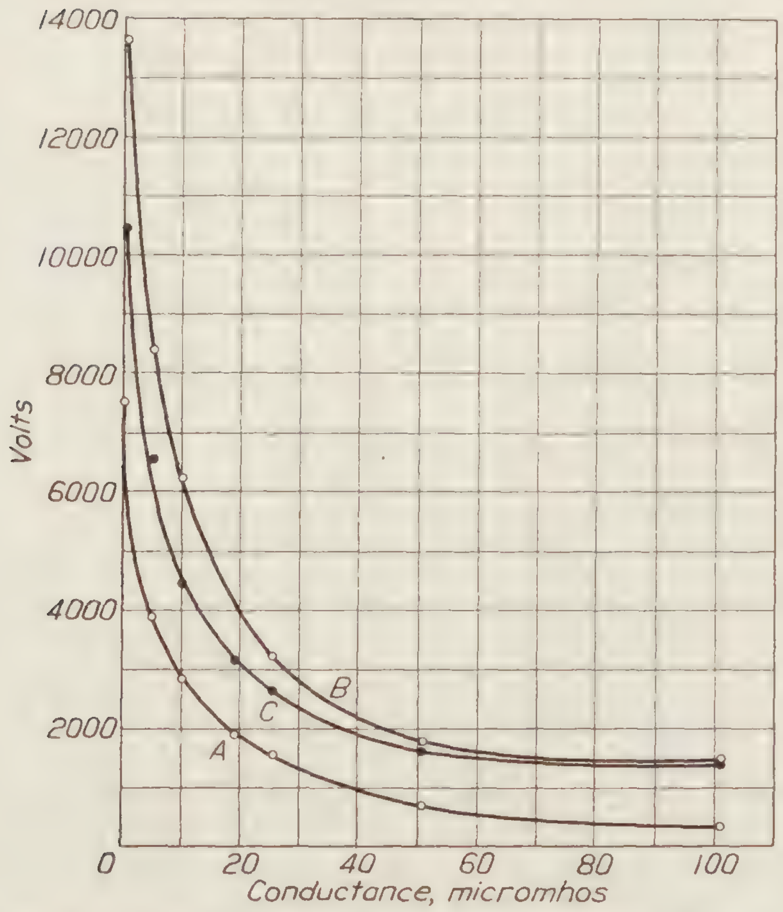


FIG. 13.—Secondary crest voltage vs. shunting conductance for magneto E (sleeve-inductor type); **A** at 50 R. P. M., **B** at 500 R. P. M., **C** same as **B** but with an additional condenser of 250 $\mu\mu$f capacitance shunting the secondary

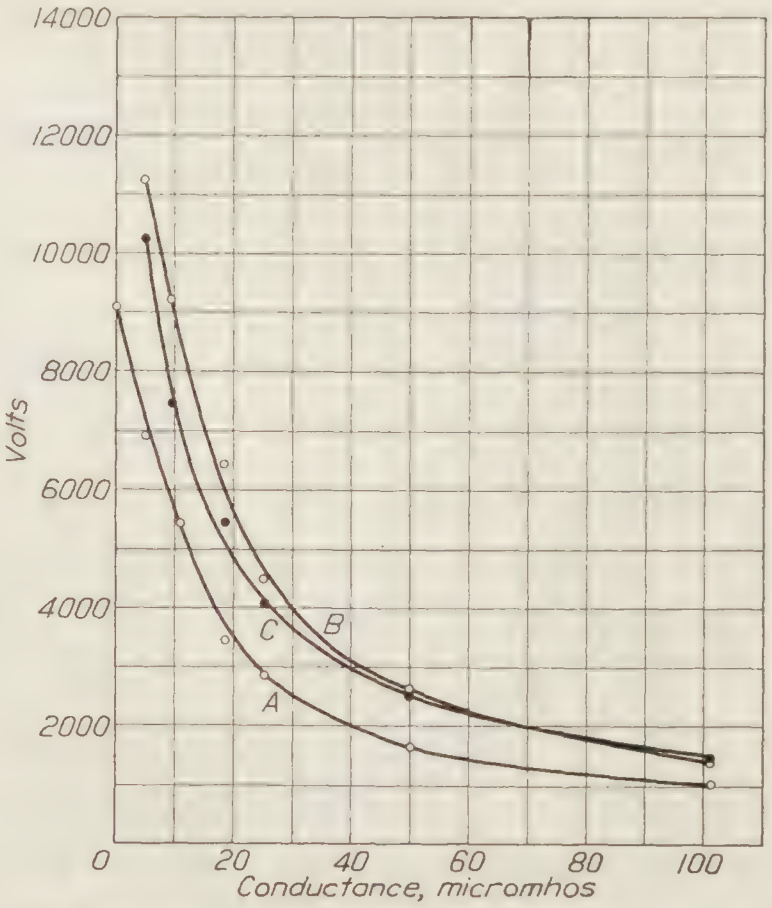


FIG. 14.—Secondary crest voltage vs. shunting conductance for magneto F (inductor type) at full advance; **A** at 50 R. P. M., **B** at 1,000 R. P. M., **C** same as **B** but with an additional condenser at 240 $\mu\mu$ capacitance shunting the secondary

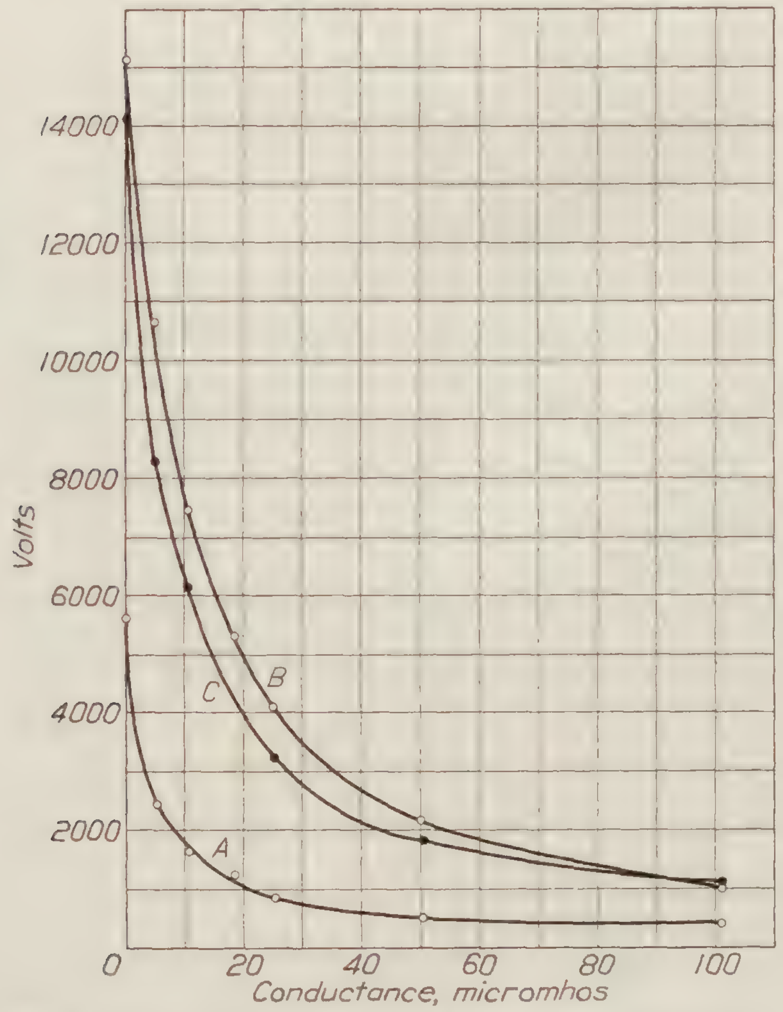


FIG. 15.—Secondary crest voltage vs. shunting conductance for magneto G (pulsating-flux type); **A** at 50 R. P. M. at full advance, **B** at 1,000 R. P. M. at full retard, **C** same as **B** but with additional condenser of 200 $\mu\mu$f capacitance shunting the secondary

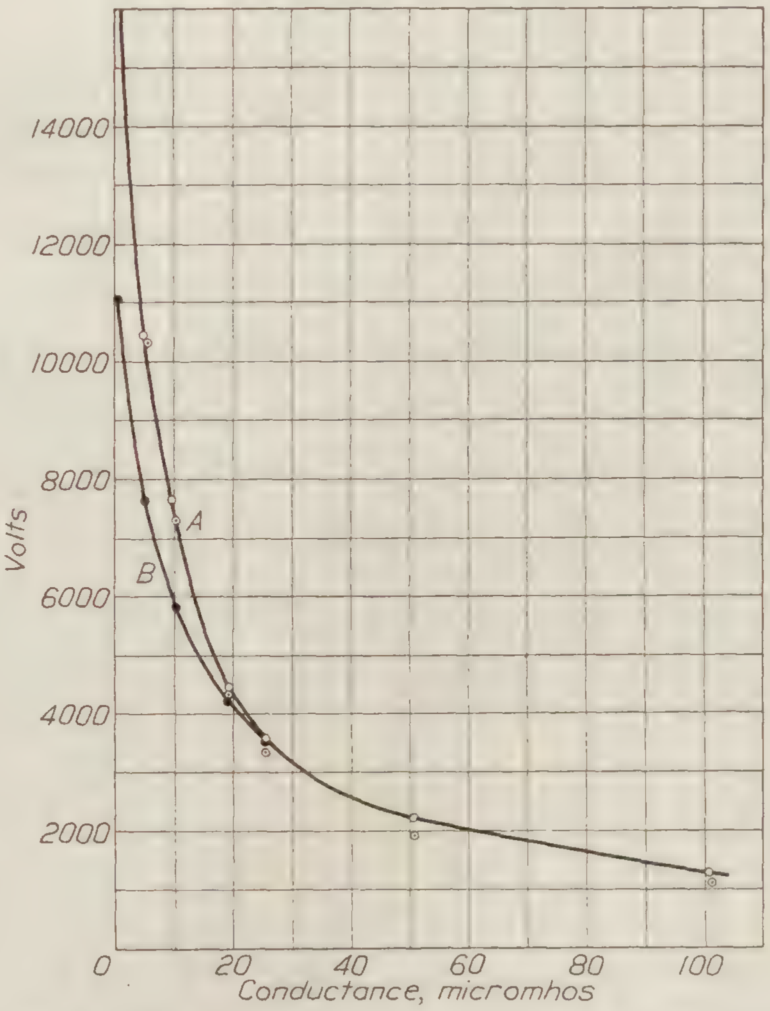


FIG. 16.—Secondary crest voltage vs. shunting conductance for 6-volt coil H; **A** at 800 sparks per minute, **B** same with an additional condenser of 330 $\mu\mu$f shunting the secondary; circles with dot indicate values observed at 5,000 sparks per minute without the condenser

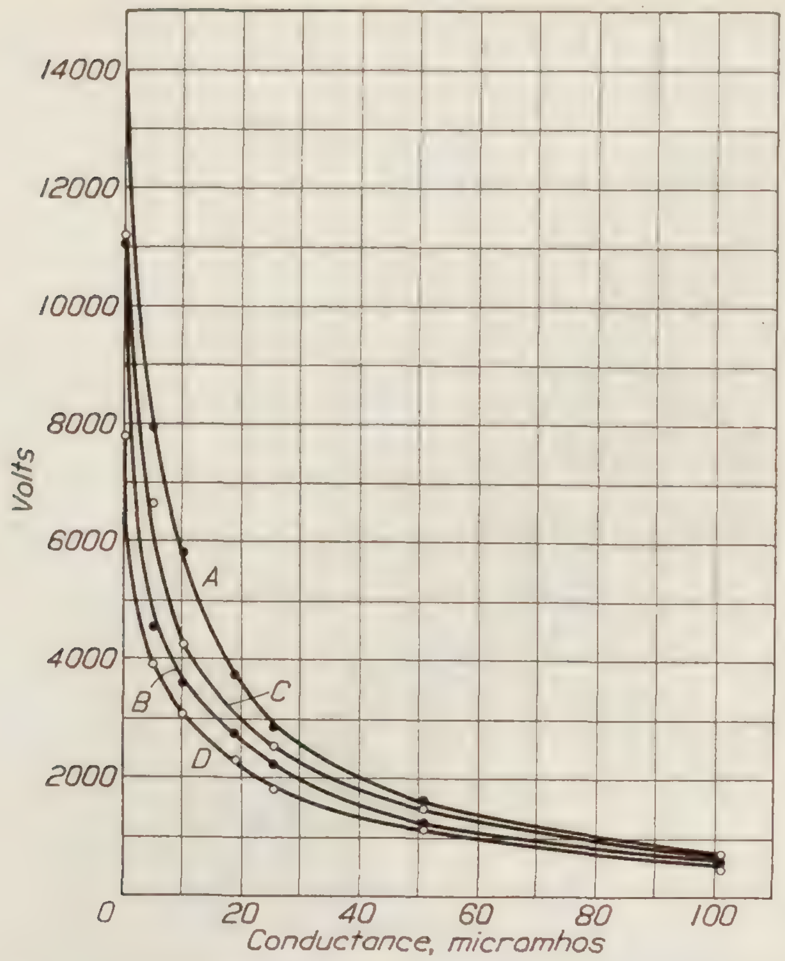


FIG. 17.—Secondary crest voltage vs. shunting conductance for 6-volt coil I; **A** at 800 sparks per minute, **B** at 5,000 sparks per minute, **C** same as **A** but with a condenser of 330 $\mu\mu$f capacitance shunting secondary, **D** same as **B** but with a condenser of 330 $\mu\mu$f capacitance shunting the secondary

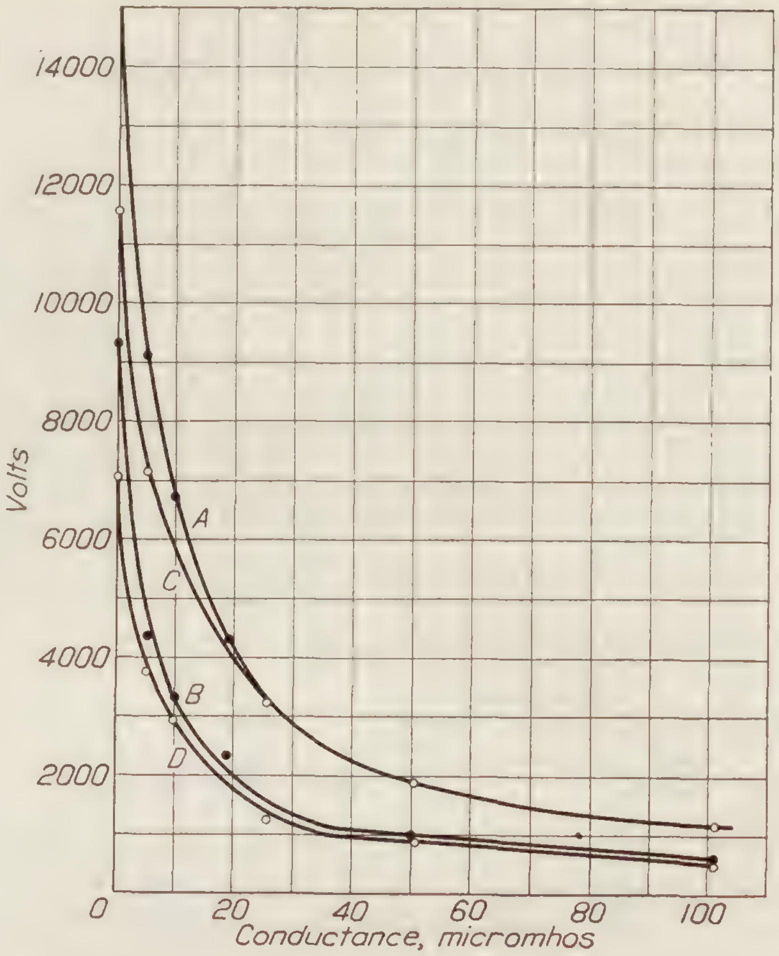


FIG. 18.—Secondary crest voltage vs. shunting conductance for 12-volt coil J; **A** at 800 sparks per minute, **B** at 5,000 sparks per minute, **C** same as **A** but with an additional condenser of 330 $\mu\mu$f capacitance shunting the secondary, **D** same as **B** but with an additional condenser of 330 $\mu\mu$f capacitance shunting the secondary

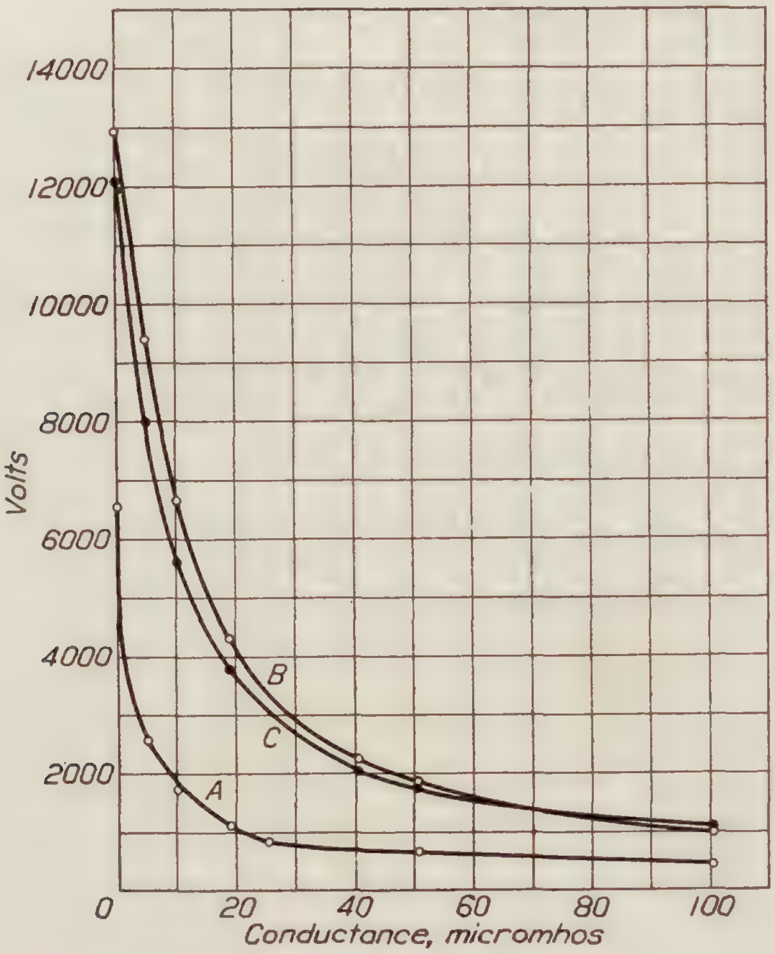


FIG. 19.—Secondary crest voltage vs. shunting conductance for magneto K (shuttle-core type) at full advance; **A** at 50 R. P. M., **B** at 1,000 R. P. M., **C** same as **B** but with an additional condenser of 240 $\mu\mu$f capacitance shunting the secondary

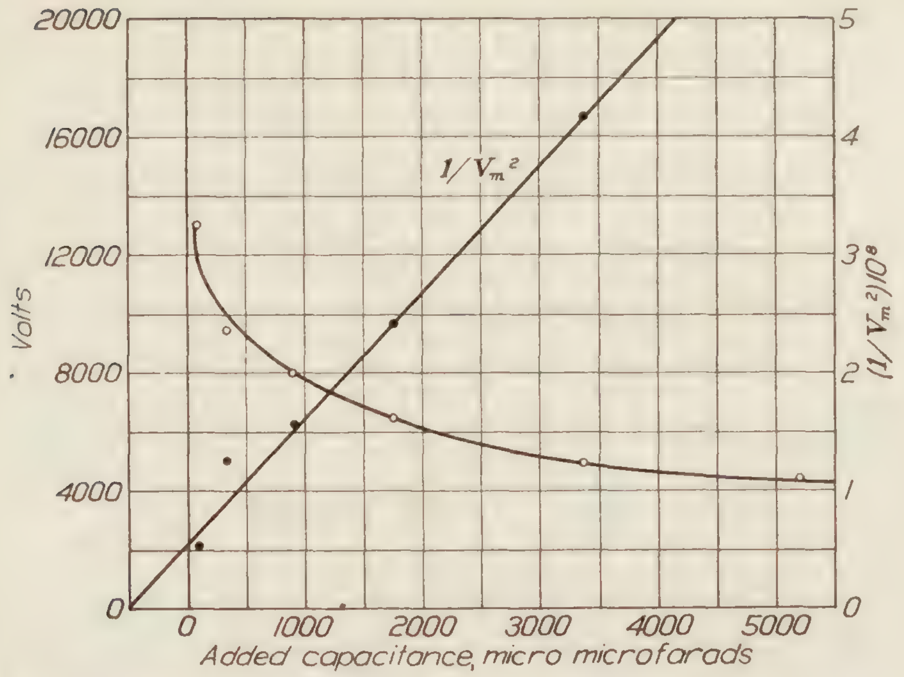


FIG 20.—Secondary crest voltage vs. shunting capacitance for magneto A (inductor type) fixed timing, 500 R. P. M. The straightl ine is a graph of $1/V_m^2$ vs. capacitance

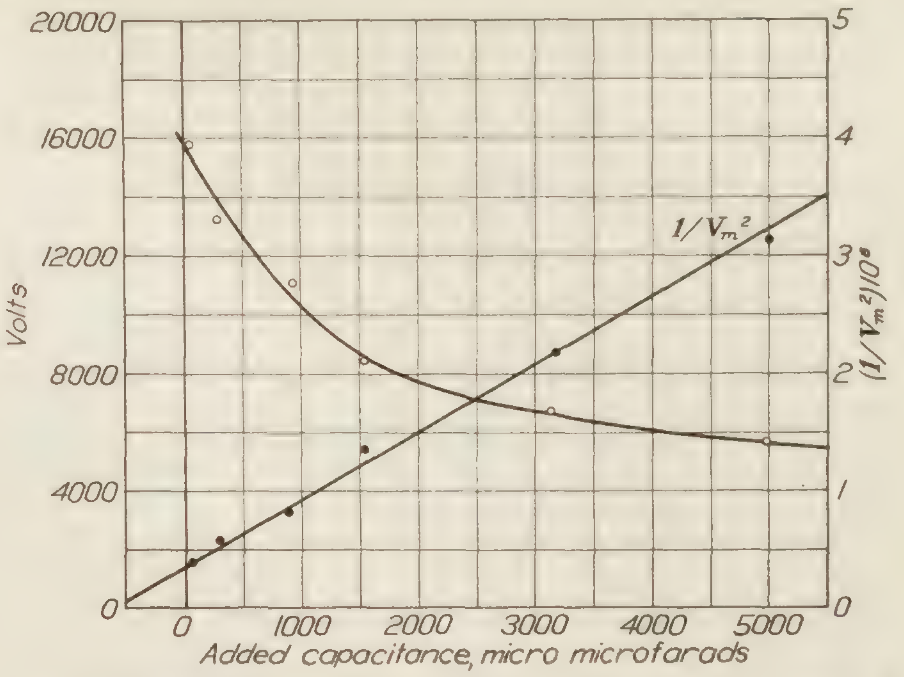


FIG. 21.—Secondary crest voltage vs. shunting capacitance for magneto B (inductor type) at full advance, 500 R. P. M. The straight line is a graph of $1/V_m^2$ vs. capacitance

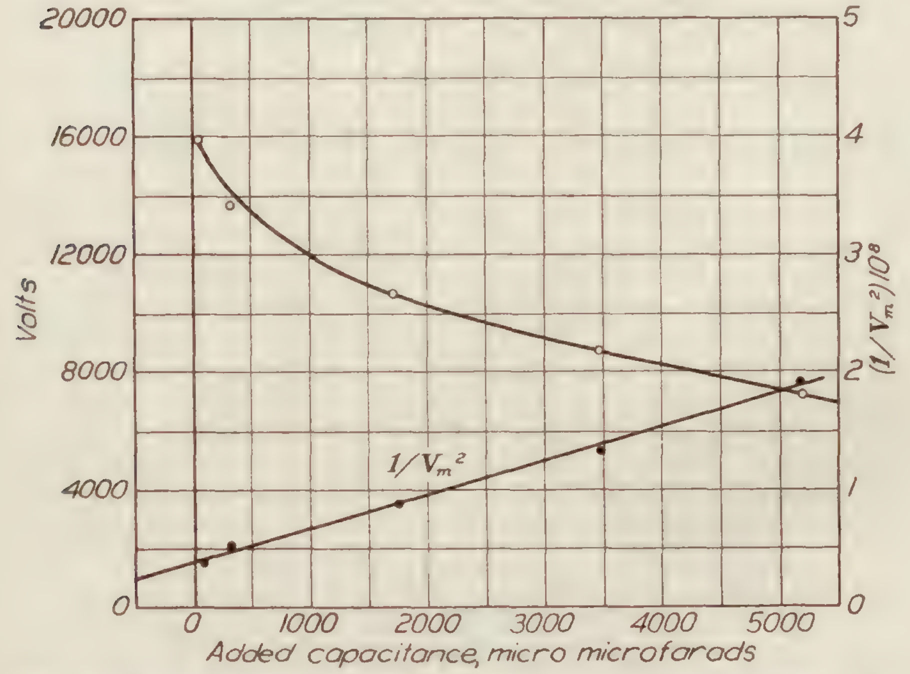


FIG. 22.—Secondary crest voltage vs. shunting capacitance for magneto C (shuttle-core type) at full advance, 1,000 R. P. M.

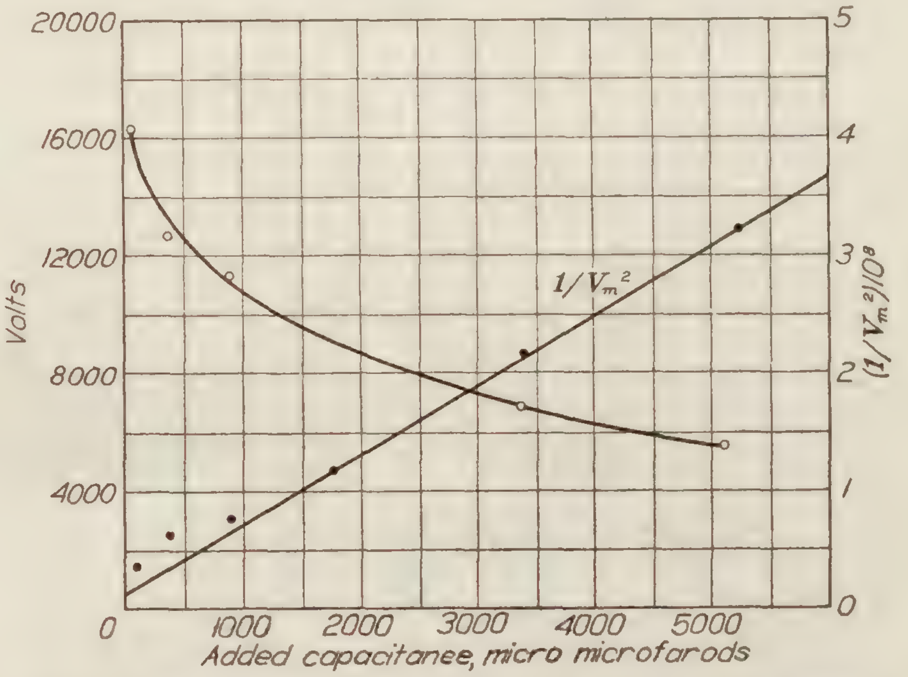


FIG. 23.—Secondary crest voltage vs. shunting capacitance for magneto D (revolving-magnet type) at full advance, 1,000 R. P. M. The straight line is a graph of $1/V_m^2$ vs. capacitance

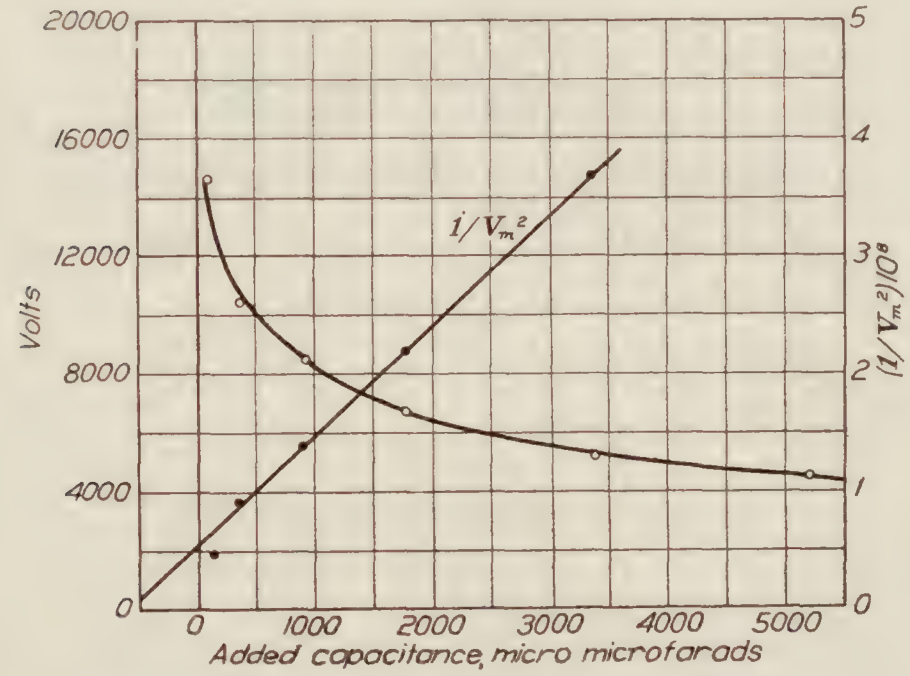


FIG. 24.—Secondary crest voltage vs. shunting capacitance for magneto E (sleeve-inductor type), fixed timing, at 500 R. P. M.

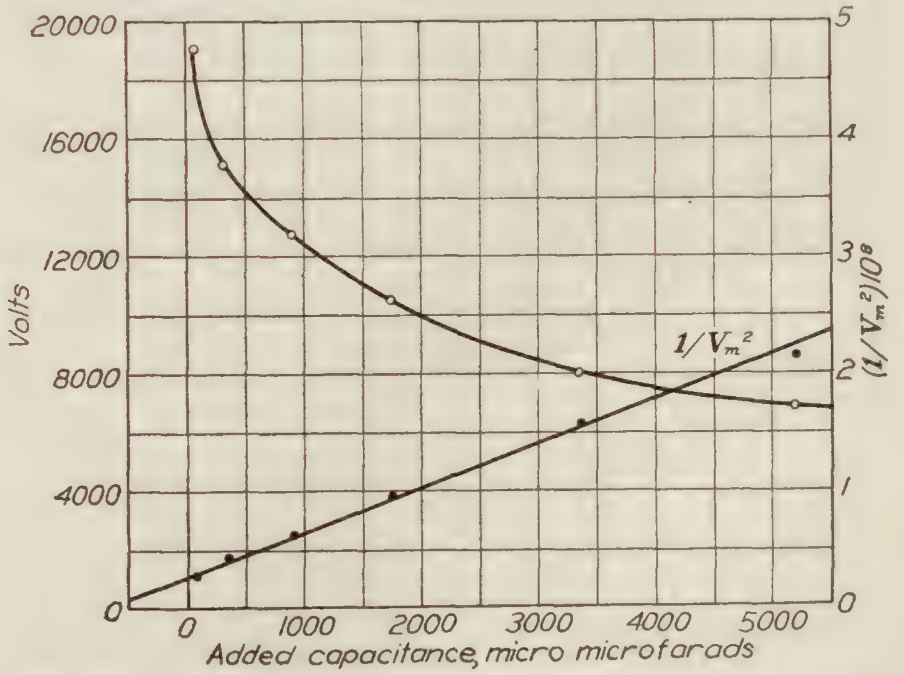


FIG. 25.—Secondary crest voltage vs. shunting capacitance for magneto F (inductor type) at full advance, 1,000 R. P. M.

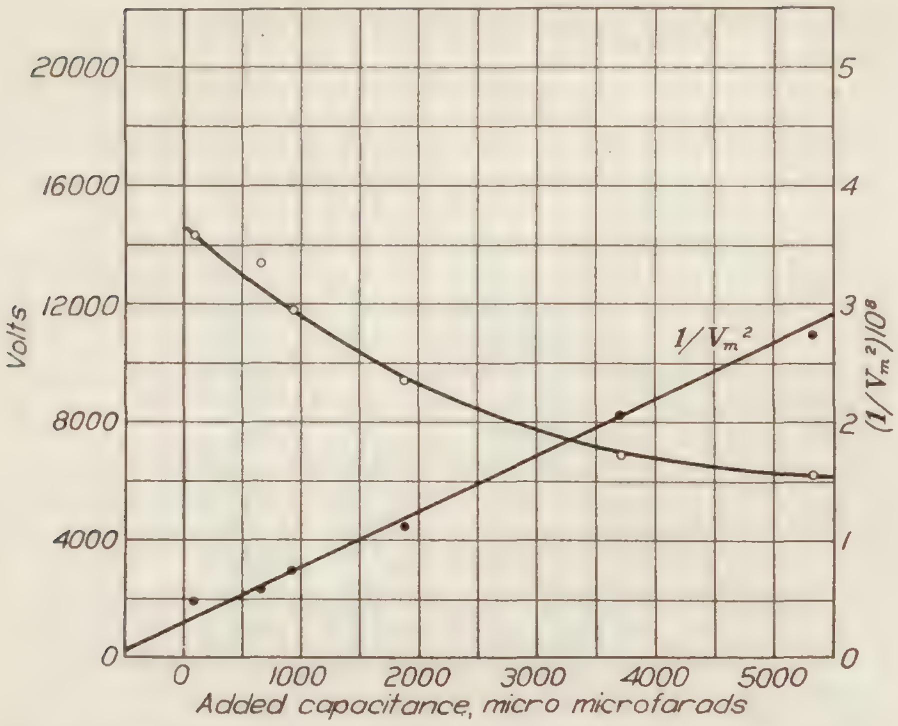


FIG. 26.—Secondary crest voltage vs. shunting capacitance for magneto G (pulsating-flux type) at 1,000 R. P. M. at full retard. The straight line is a graph of $1/V_m^2$ vs. capacitance

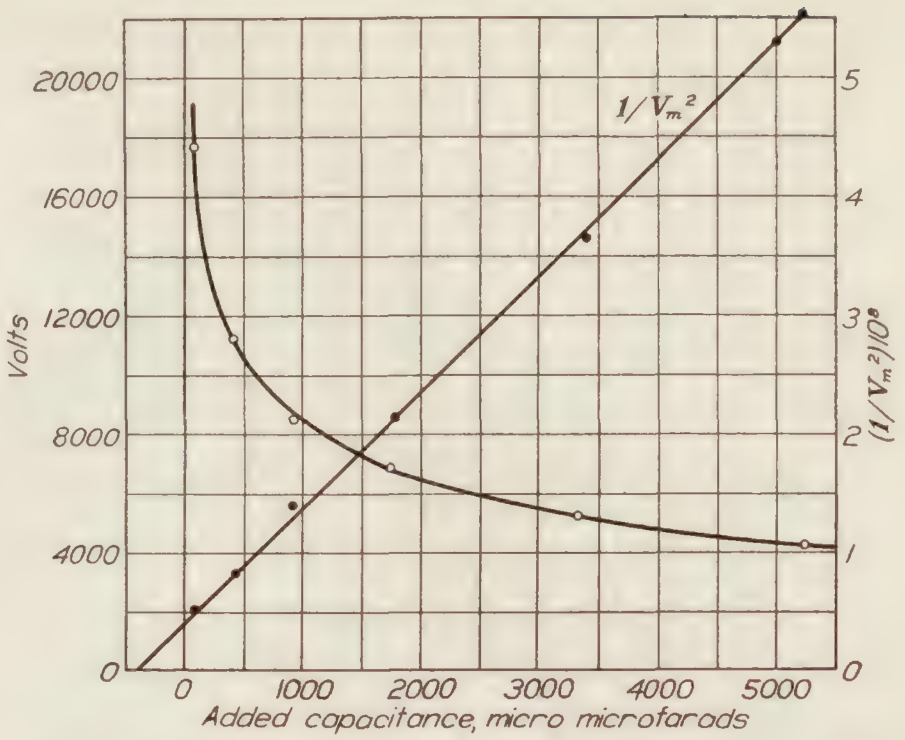


FIG. 27.—Secondary crest voltage vs. shunting capacitance for 6-volt coil H at 800 sparks per minute. The straight line is a graph of $1/V_m^2$ vs. capacitance

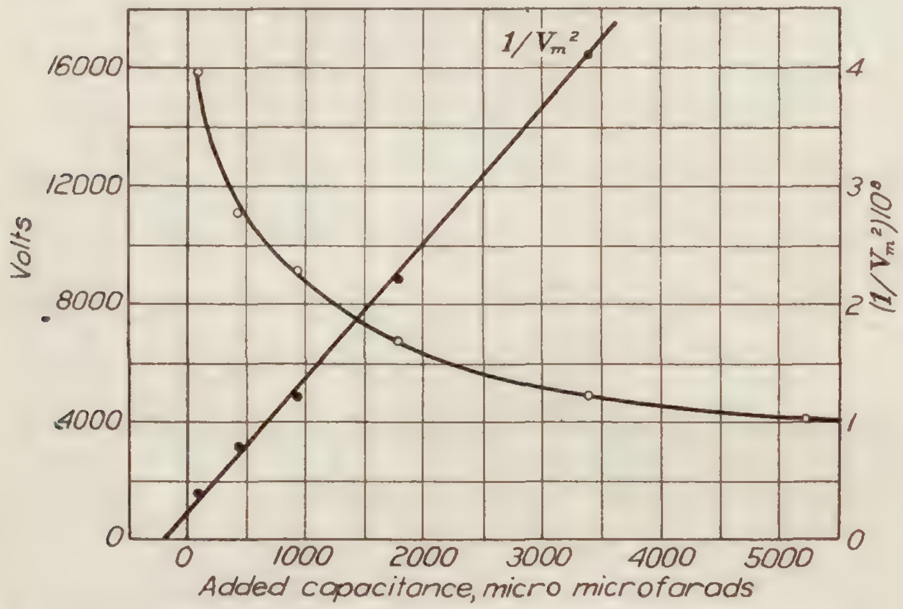


FIG. 28.—Secondary crest voltage vs. shunting capacitance for 6-volt coil I at 800 sparks per minute. The straight line is a graph of $1/V_m^2$ vs. capacitance

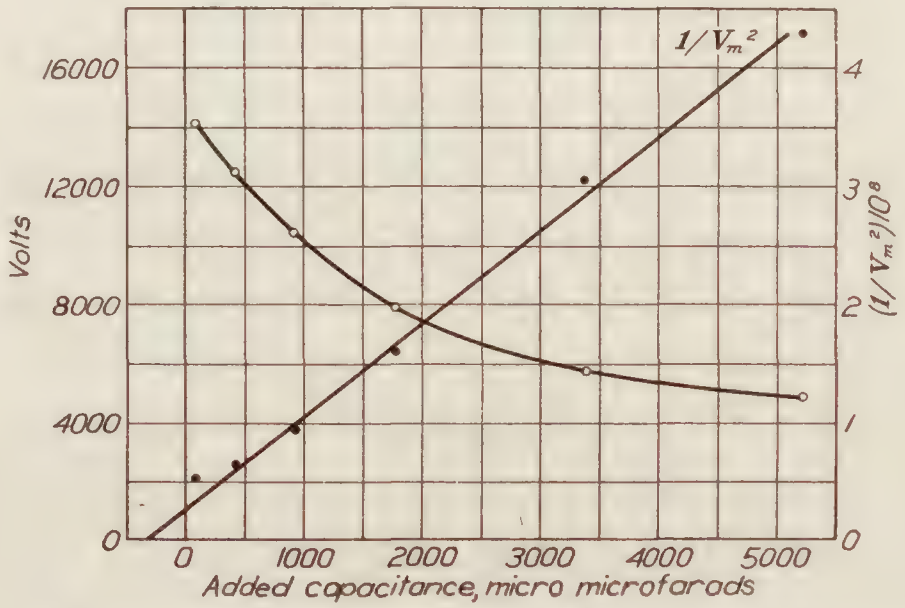


FIG. 29.—Secondary crest voltage vs. shunting capacitance for 12-volt coil J at 800 sparks per minute. The straight line is a graph of $1/V_m^2$ vs. capacitance

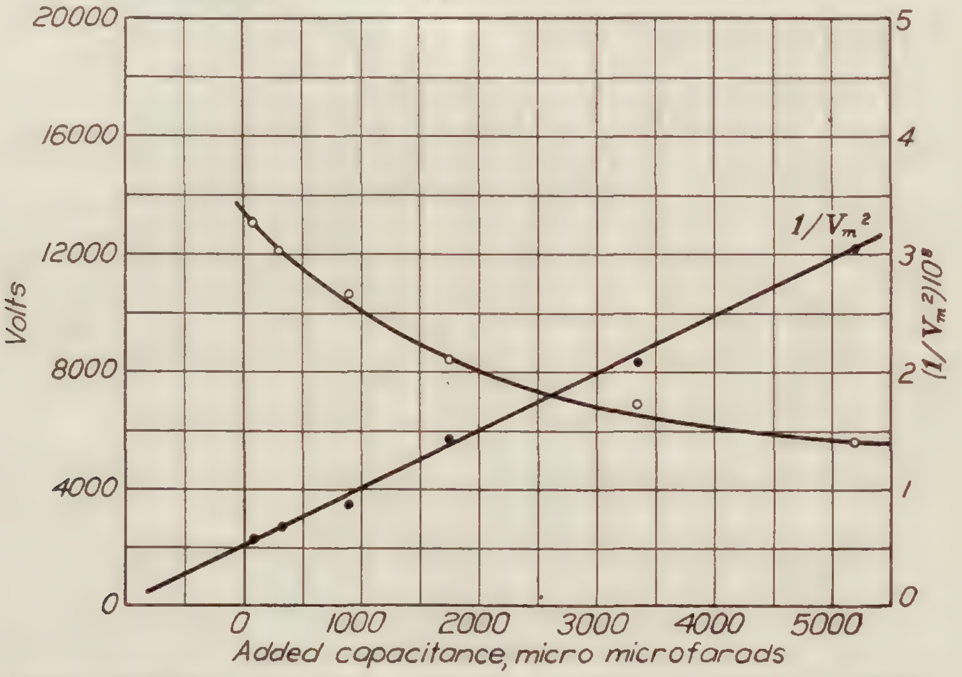


FIG. 30.—Secondary crest voltage vs. shunting capacitance for magneto K (shuttle-core type) at full advance, 1,000 R. P. M.

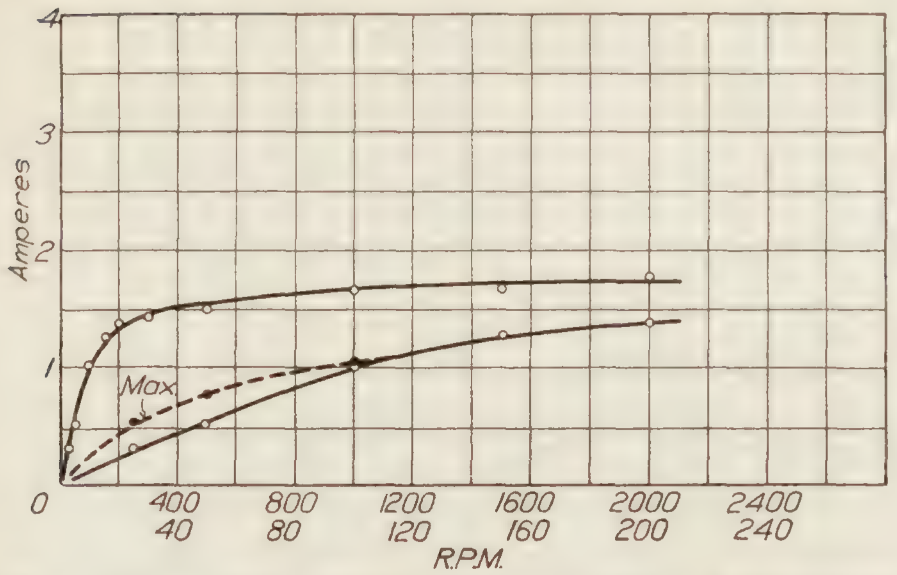


FIG. 31.—Primary current at break vs. speed for magneto A (inductor type), fixed timing. Lower curves show low-speed values to a larger scale of speed. Dotted curve shows maximum value of current which occurred before break at low speeds

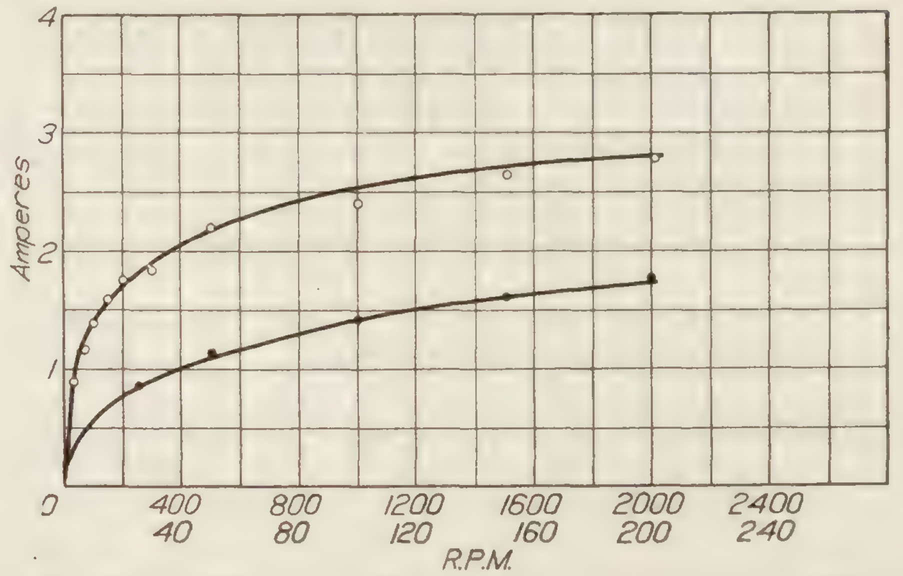


FIG. 32.—Primary current at break vs. speed for magneto B (inductor type) at full advance. Lower curve shows low-speed values to a larger scale of speed

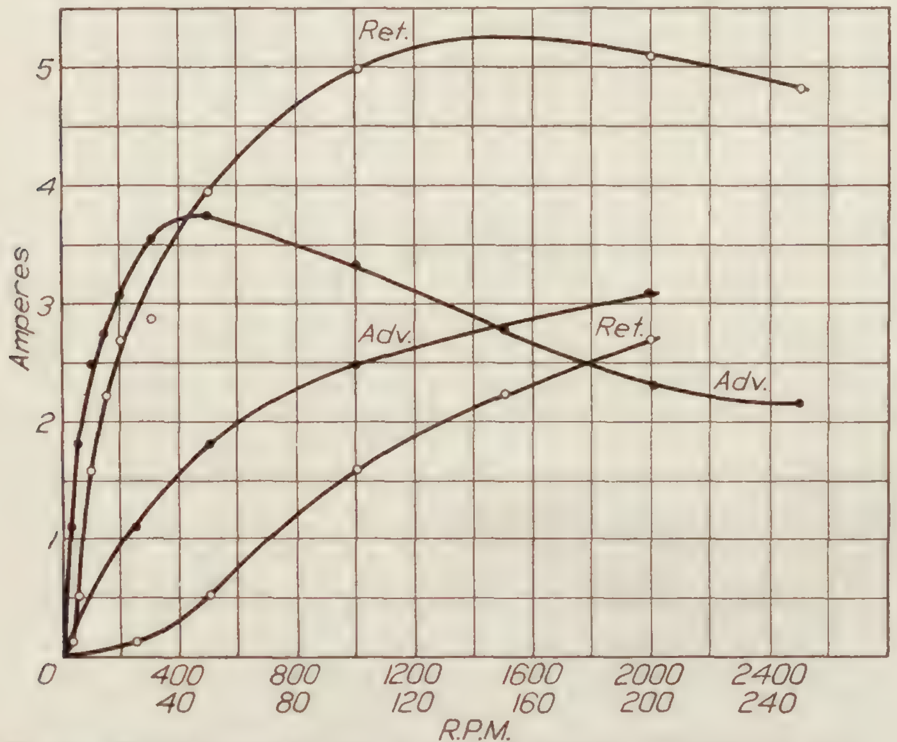


FIG. 33.—Primary current at break vs. speed for magneto C (shuttle-core type). Lower curves show low-speed values to a larger scale of speed

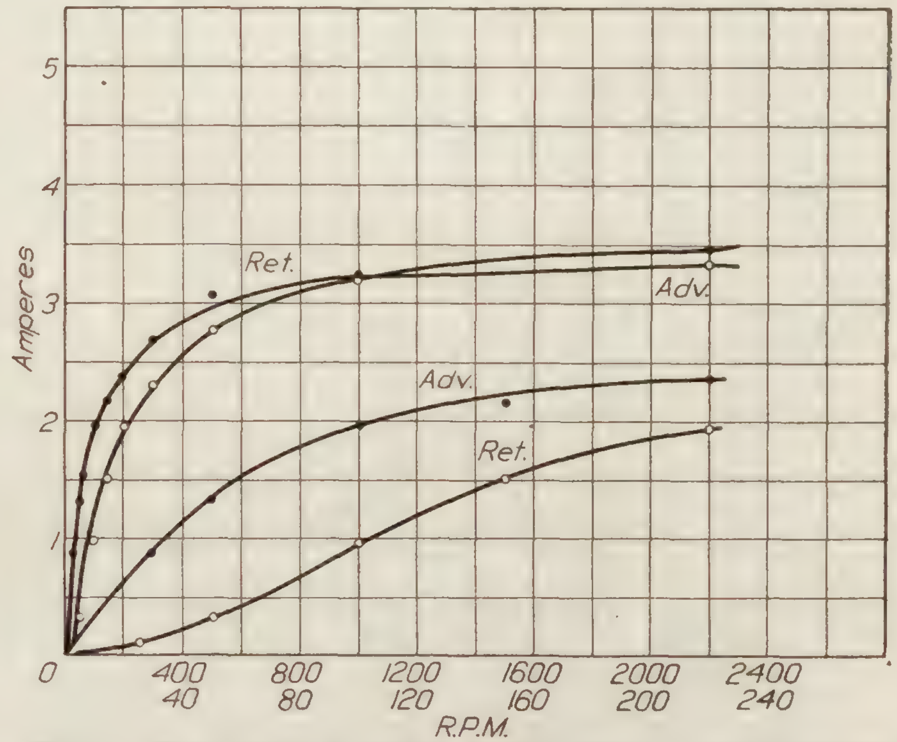


FIG. 34.—Primary current at break vs. speed for magneto D (revolving-magnet type). Lower curves show low-speed values to a larger scale of speed

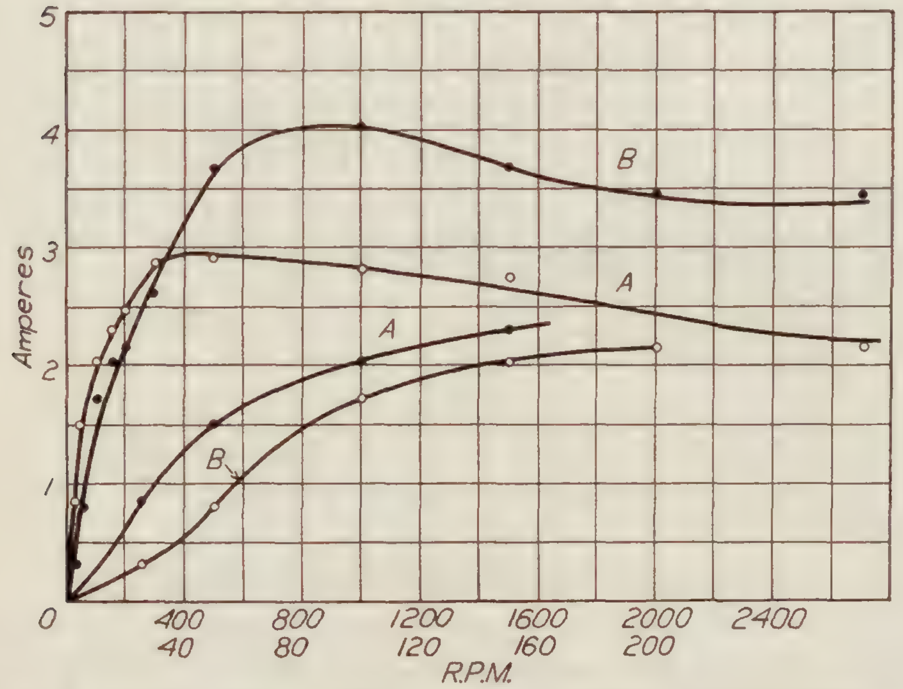


FIG. 35.—Primary current at break vs. speed for magneto E (sleeve-inductor type), fixed timing. Alternate waves differ. Crest of wave **A** occurs later with respect to "break" than that of wave **B**

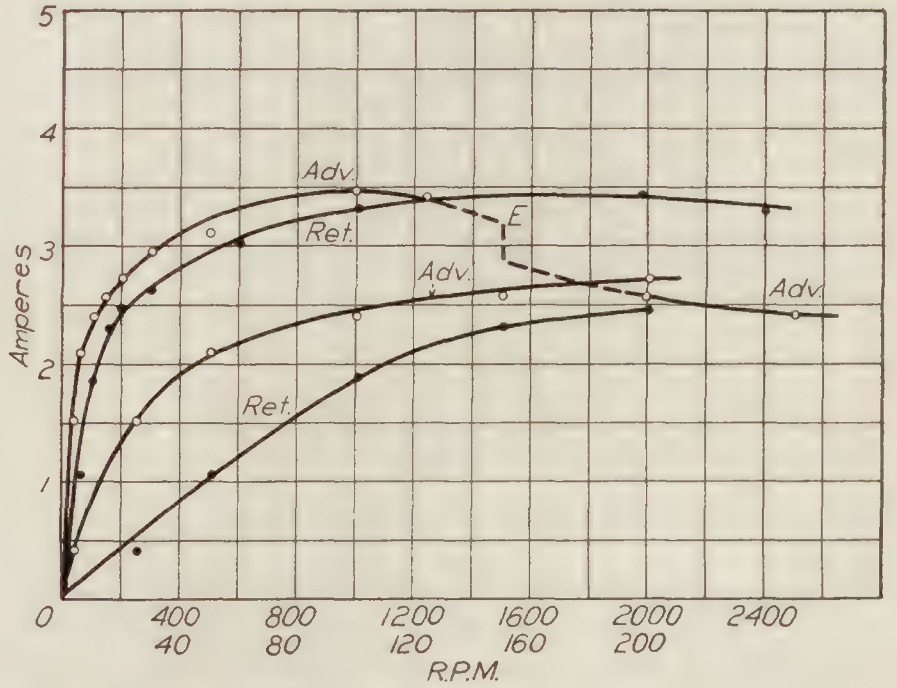


FIG. 36.—Primary current at break vs. speed for magneto F (inductor type). Lower curves show low-speed values to a larger scale of speed. Break in "advanced" curve at **E** is caused by occurrence of an "extra" spark at high speed which interferes with building up of current for the following regular spark

In the case of the coils I and J, the curves shown in Figure 38 were obtained by computation as follows: An oscillogram taken at slow speed on each coil gave a record of the rise of current with time. Points were scaled from these oscillograms and the quantity log $\frac{I}{I_0}$, where I_0 is the final steady value of current was plotted as ordinate against the time at which the current had the value I as abscissa. The resulting graph was in all cases very closely a straight line indicating that the inductance of the circuit was practically constant. The time constant $\frac{L_1}{R_1}$ of the circuit can be computed from the slope of this line and is given in column 18 of Table 2. The currents at break for various cam speeds were then computed from the equation

$$I = I_0\left(1 - e^{\frac{-R_1 a t_0}{L_1}}\right) \qquad (1)$$

When t_0 = time interval between sparks.

a = fraction of time that the breaker is closed.

$\frac{L_1}{R_1}$ = time-constant of circuit.

$I_0 = \frac{E}{R_1}$ = final current at low speeds.

The points indicated by the solid circles in Figure 38 show values obtained directly by oscillograms taken at the corresponding speeds and serve to verify the correctness of the plotted curves.

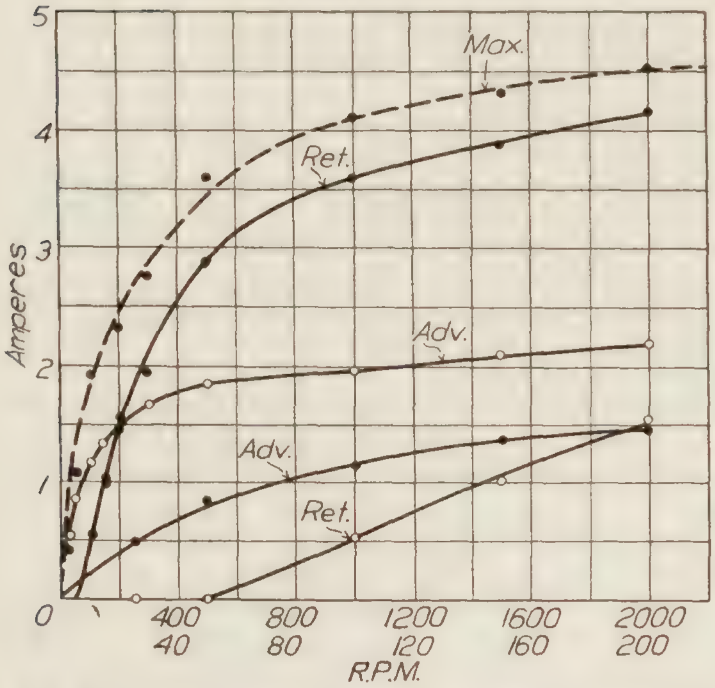


FIG. 37.—Primary current at break vs. speed for magneto G (pulsating-flux type). Lower curves show low-speed values to a larger scale of speed. Dotted curve shows crest value of current wave when operating at full retard

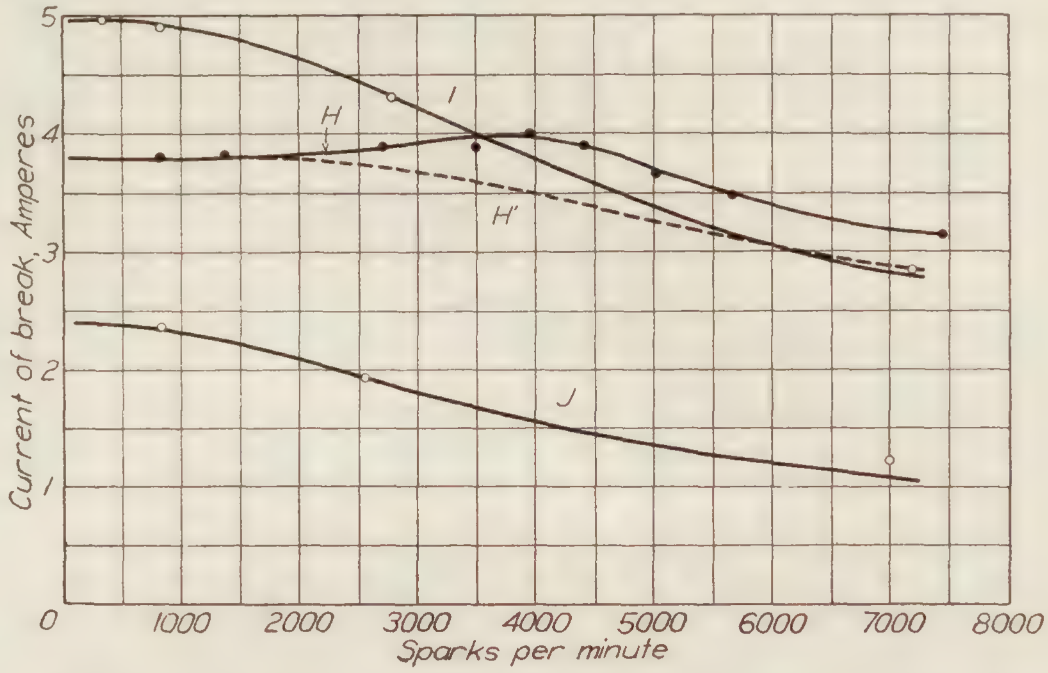


FIG. 38.—Primary current at break vs. speed in sparks per minute for coils: H (6-volt), I (6-volt), and J (12-volt). The rise in curve H results from action of ballast resistor coil, and the dotted curve H' shows the values which would result if the resistance of the circuit remained constant

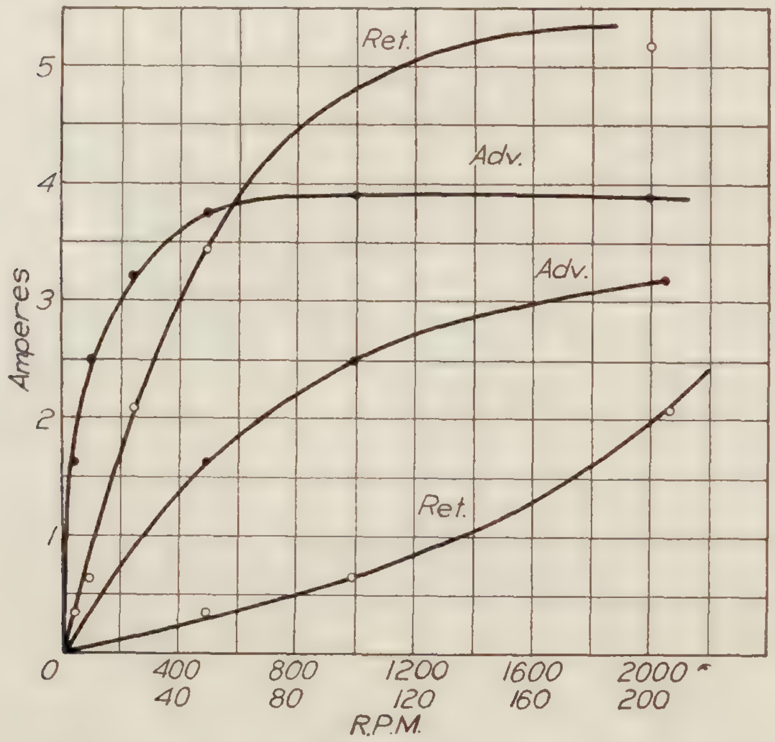


FIG. 39.—Primary current at break vs. speed for magneto K (shuttle-core type). Lower curves show low-speed values to a larger scale of speed

System H was provided with a ballast resistor of material having a high-temperature coefficient of resistance. The main object of such a resistor is to limit the amount of current which would flow if the engine should stop with the breaker points in contact, and thus avoid overheating the primary winding of the spark coil. However, the presence of this resistor has the further effect of changing the rate at which the primary current falls off with increasing engine speed as is shown by a comparison of curves H and H' of Figure 38. The former (solid) curve shows the values of current at break actually observed with the oscillograph, while the latter (dotted) curve shows the values which would result if the resistance and inductance of the circuit had remained constant at the different speeds. An analysis of a typical oscillogram showed that even in this system the growth of current was quite closely in accordance with the simple exponential law, and hence that the ballast resistor did not change appreciably in temperature or resistance during the course of a single cycle, although these values shift materially when the engine speed is altered to a new value.

Auxiliary measurements were also made on the voltage generated when the magnetos were rotated on open circuit. It was found that both the crest value and the effective (root-mean-square) value of primary voltage were quite closely proportional to the speed of rotation. In columns 10 and 11 of Table 1 are given the effective and crest voltage for a speed of 1,000 R. P. M., and in column 12 the quotient of these values. Since the ratio of crest to effective value for a sine wave is only 1.41, whereas in these magnetos values as high as 4.0 were obtained, it will be seen how very peaked the magneto waves are.

As a basis for a further analysis of the performance of the spark generators, measurements were made of the flux turns linking the secondary winding for various angular positions of the armature and for various values of primary current at each position. (Reference 6.) By dividing the change in flux turns between any two conditions by the corresponding change in current, a value is obtained for the inductance of the circuit, and values thus obtained are given in columns 9 and 10 of Table 2.

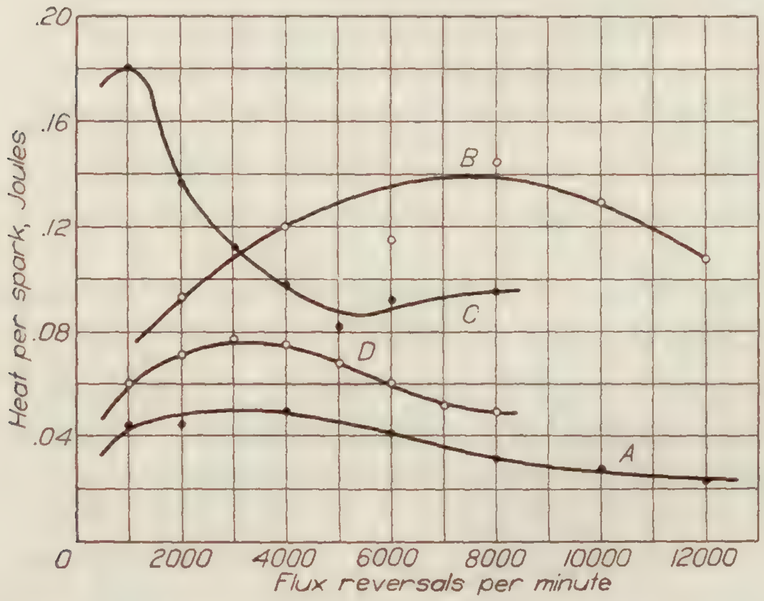


FIG. 40.—Heat energy (in joules) disspiated in spark gap vs. speed (in flux reversals per minute) for systems **A**, **B**, **C**, **D**, operating at full advance

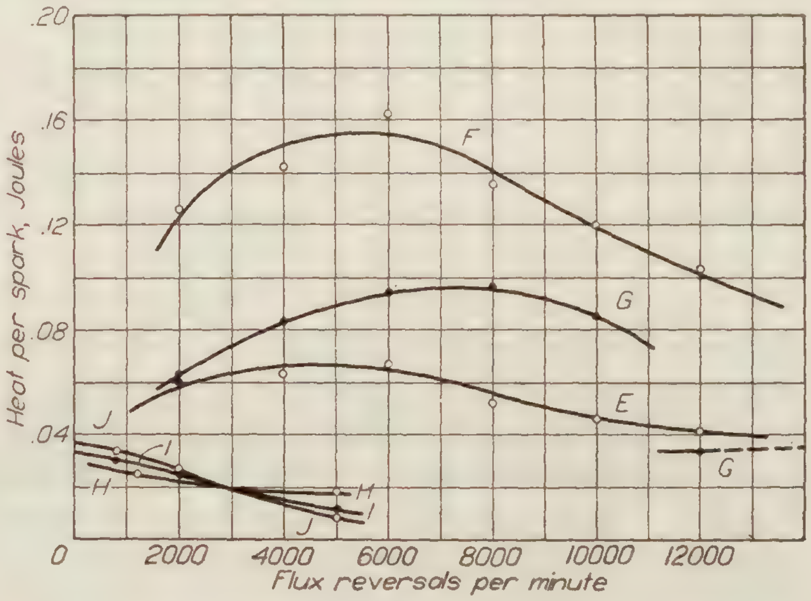


FIG. 41.—Heat energy (in joules) dissipated in spark gap vs. speed (in flux changes per minute) for systems **E**, **F**, **G**, **H**, **I**, and **J**, operating at full advance. The break in curve **G** results from serious arcing at the breaker points

The area between a graph of flux turns vs. current and the axis of flux turns also gives the energy change occurring between the two conditions indicated by the ends of the graph. The figures given in column 9 of Table 3 are values thus obtained for the maximum possible energy which could be transformed and delivered to the spark gap by an ideal magneto having the same magnetic circuit as the actual machine but free from all sources of energy loss such as resistance and eddy currents. Column 8 indicates the corresponding values of current at break which would be attained. While these are limiting figures, unattainable in practice, they nevertheless form a useful standard against which to compare the actual performance. It was, however, impracticable in most cases to carry the measurements to the full current value given in column 8 and these data are therefore uncertain to the extent of this extrapolation.

The figures in column 10 which indicate the energy per spark available at the instant of break when the generator is operating at 2,000 sparks per minute at full advance were obtained by combining the flux-meter data with the values of current at break found by the oscillograph.

The figures in column 11 similarly give the energy available when operating at 50 R. P. M., full advance.

The actual heat energy liberated in the spark gap was also measured on each system at several speeds by causing the spark to occur inside a hollow copper block (Reference 7) which served as a calorimeter. The spark occurred between blunt nickel electrodes spaced 2.1 mm. apart. The results of these measurements are plotted in Figures 40 and 41. The ordinates give the energy in joules per spark (1 joule = 0.24 calories = 1 watt-second) and the abscissæ the speed of the spark generator expressed as flux reversals (or changes) per minute.

A considerable number of other supplementary measurements were made to give the necessary data for a detailed study of the cause of the observed characteristics. The results are given in the tables.

The ratio of turns and the coupling coefficient were obtained with an accuracy of better than 1 per cent by the null method previously described by one of the authors. (Reference 8.) The actual number of turns could be estimated only approximately from measurements made by means of an exploring coil of a known number of turns wound over the regular windings. The flux turns linking this coil were compared with those linking the secondary winding by an opposition method similar to that used for the ratio measurement. This comparison was made for flux changes caused in two ways: (*a*) by energizing an external electromagnet applied to the extremities of the core; and (*b*) by sending current through the primary winding. A consideration of the probable flux paths in the two cases shows that the apparent number of secondary turns is too small in case (*a*) and too large in case (*b*). The mean value is given in column 3 of Table 2. Column 2 gives the corresponding number of primary turns.

In the best case the difference between the upper and lower limits thus obtained was only 2.5 per cent, while in the worst case it was 48 per cent. In the case of system F winding data were kindly supplied by the manufacturer, and the experimental values were found to agree with these to 1 per cent.

An attempt was made to obtain a quantitative basis for estimating the effects of eddy currents during the abrupt flux changes occurring in the normal operation of these spark generators by observing the corresponding effects produced when the generators were subjected to harmonically alternating flux changes of various frequencies. For this purpose the secondary circuit of each system was connected in one arm of a bridge circuit supplied with alternating current. (Reference 9.) A number of frequencies from 25 cycles to 3,000 cycles per second were used, and at each frequency the apparent resistance and inductance of the winding were measured. Also the capacitance between the high-tension terminal of the secondary and the frame or core was determined by balancing a fifth bridge arm, consisting of a variable condenser and resistance connected between the frame of the magneto and the opposite supply terminal of the bridge. The voltage applied to the winding was kept proportional to the frequency and was 230 volts per 1,000 cycles, so that all the observations on any one system were made at practically the same flux density. The decrease in inductance with increase of frequency which was observed can therefore be properly attributed to eddy currents. In columns 12, 13, and 11 of Table 2 there are given the effective inductances and resistances of the secondary windings at 3,000 cycles per second and the corresponding inductance at zero frequency as found by extrapolating the observed curve. These values correspond to the fully advanced position of the breaker, and have been corrected for the effect of the internal capacitance of the winding. The difference between their values and those in columns 9 and 10 of Table 2 arises from the different flux density at which the magnetic circuit was working. From the decrease in inductance and the increase in resistance it is possible to estimate for any frequency the time constant T_e of the eddy current circuit and the coupling coefficient $k^2{}_e$ by which it is coupled magnetically to the windings. These values are given in columns 8 and 9 of Table 5.

In order to obtain a value for the internal capacitance C_w (Reference 10) of the windings, which is needed to correct the alternating-current bridge data, a series of capacitance measurements were made at radio-frequencies in the range from 40 to 300 kilocycles. It was found that most of the coils showed a change of about 15 $\mu\mu$f in effective capacitance at about 100 kilocycles. Presumably this is the result of a local resonance point in the winding, which cuts out part of the possible capacitance at the higher frequencies. Consequently the larger value corresponding to lower frequencies was used in later computations and is given in column 5 of Table 4.

The value of the terminal capacitance C_t as observed with the alternating-current bridge is given in column 6. The capacitances of the primary condensers were measured directly by a microfarad meter with the results given in column 2. Combining these values according to the relation

$$C_o=\frac{C_1}{n^2}+C_t+\frac{4}{3}\,C_w \tag{2}$$

gives the total effective capacitance of the system referred to the secondary side and the values thus obtained are given in column 7 of Table 4. The factor $\frac{4}{3}$ enters because in operation there is a uniform voltage gradient along the winding while in the measurements at radio-frequency the voltage distribution being determined solely by capacitances is such as to minimize the capacitance. The capacitance (C_g) from the inner layer of the winding to the core is given in column 4, but is of importance only in the case of two-spark magnetos.

DISCUSSION OF RESULTS

As previously indicated, the most important electrical performance characteristic of a spark generator is the secondary crest voltage at the instant of break, V_m. This voltage depends upon the primary current at break I_b and the values of shunting resistance S, and capacitance C_a, which may be connected in parallel with the secondary. An examination of the observed data shows that there are certain theoretical and empirical relationships between these quantities and the electrical constants which are useful in the comparison of spark generators and in predicting the behavior of a given spark generator under various conditions.

The first relation is that between the maximum induced voltage and the primary current at break. As can be seen from Figures 1 to 8, in the magneto systems the observed crest voltage increases with speed until at a speed of about 200 R. P. M. it reaches such a high value that sparks are produced at the safety gap. For higher speeds the observed voltage is merely the sparking voltage of the gap and bears no direct relation to the magneto. For speeds less than this value, however, there is a very definite and simple relation between the crest voltage V_m, and the current at break I_b. From the simple theory of the magneto, it would be expected that (Reference 11)

$$V_m=\frac{I_b}{n}\,F\sqrt{\frac{L_2}{C_o}}+E_r \tag{3}$$

where L_2 and C_o are the inductance and capacitance of the equivalent single-coil model and F is a factor resulting from the damping effect of the resistance and eddy currents. E_r is the electromotive force acting in the secondary winding as the result of the rotation of the armature at the instant of maximum voltage. When the magneto is operating with its breaker retarded E_r has decreased to nearly zero before the breaker opens and may therefore be neglected. At advance, however, the crest of the induced voltage occurs while an appreciable fraction of the rotational E. M. F. is still acting. Nevertheless, since in the speed range which is here of interest both E_r and I_b are nearly proportional to the speed, it would be expected that V_m would be proportional to I_b. This relation was tested for the various magnetos where data were available over a considerable range of current values and the proportionality was found to hold within limits of ±6 per cent in most cases and ±12 per cent in all but one case. The ratio V_m/I_b may be called the "impulsive impedance" of the windings and denoted by the letter Z_m. Values of this quantity referred to the secondary side for the several systems operating at full advance are given in column 15 of Table 2.

From the value of L_2 and C_o for corresponding conditions given in column 10, Table 2, and column 7, Table 4, the factor $Z_2=\sqrt{\frac{L_2}{C_o}}$ can be computed with the result given in column 14, Table 2. Comparing these figures with those in column 15 shows that the factor F must have the values given in column 16 to account for the losses and eddy current effects. The frequency of oscillation of a circuit having these values of inductance and capacitance is given in column 17, Table 2. The actual frequency of the oscillations occurring immediately after "break" is probably materially higher than this because of the effects of eddy currents in reducing the effective inductance.

The relation between secondary crest voltage V_m and shunting resistance S, as shown by the curves of Figures 9 to 19, is less readily determined on theoretical grounds. At very large values of S the crest voltage approaches the limiting value of $I_b\ Z_m$ or $\frac{I_b Z_2 F}{n}$ and becomes independent of S. If the magnetic coupling between the two windings of the magneto or coil were perfect (Reference 12) so that M was exactly equal to $\sqrt{L_1 L_2}$, then for very low values of S the crest voltage would approach the value $V_m = \frac{I_b S}{n}$. However, in actual spark generators as shown by the data in columns 5 and 6 of Table 2, the coupling although close, is not perfect. It can be shown by theoretical considerations that in such cases, if the primary resistance is small, the current in the primary winding will oscillate and the maximum secondary voltage will be produced when the currents in the primary and secondary circuits are flowing in opposite directions. In such a case the crest voltage approaches the value $V_m = \frac{2 I_b S}{n}$ as the damping effects become small.

For values of S intermediate between these two limiting conditions even the simplest forms of theoretically equivalent circuit lead to very complicated expressions for the relation between V_m and S. However, the simple empirical equation

$$V_m = \frac{2 I_b S Z}{n(2S + Z)} \tag{4}$$

has been found to fit the observations fairly closely, where Z is to be regarded as an empirical constant which has the dimensions of an impedance, and becomes identical with nZ_m if the empirical equation fits exactly when the secondary circuit is open.

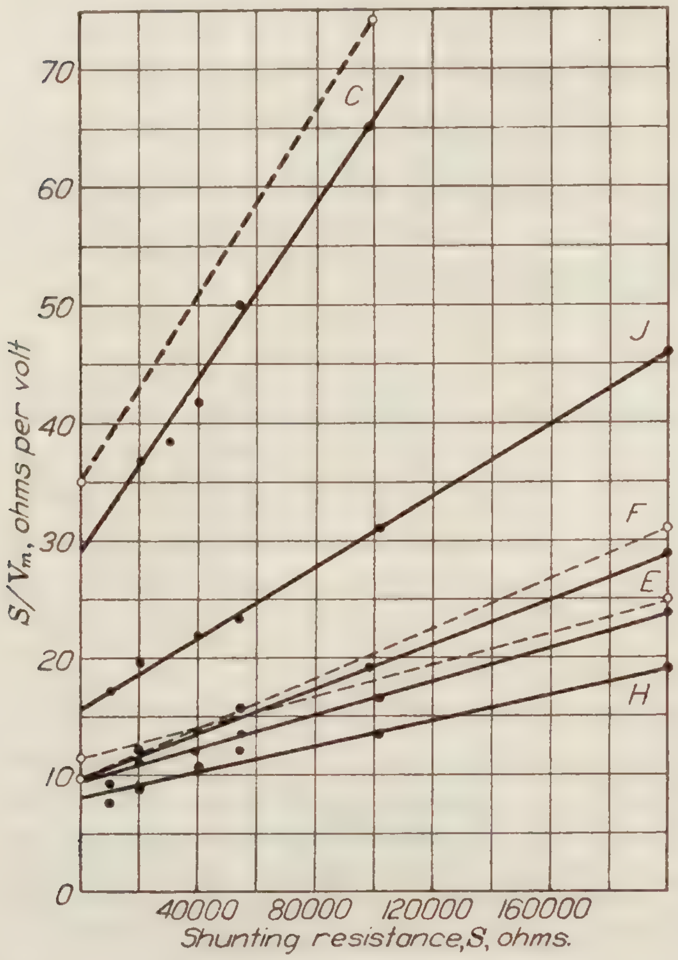


FIG. 42.—Solid lines are graphs showing the applicability of the empirical equation

$$V_m = \frac{2 I_b S Z}{n(2S + Z)}$$

for the effect of shunting resistance (S) on the secondary crest voltage (V_m). Abscissas are values of S. Ordinates are corresponding values of S/V_m. If the formula were exact, these lines should be straight, the intercept should be $n/2I_b$, and the slope should be $n/I_b Z$. Solid circles show observed values on magneto C at 50 R. P. M., full retard; magneto E at 500 R. P. M.; magneto F at 50 R. P. M., full advance; coil H at 800 sparks per minute; coil J at 5,000 sparks per minute. Dotted lines show the same graph as determined by values of I_b, n, and Z, measured separately

The easiest test of this equation is obtained by plotting the quantity $\frac{S}{V_m}$ as ordinate against S as abscissa. If the above equation holds, the result should be a straight line as appears from rearranging equation (4) to give

$$\frac{S}{V_m} = \frac{n}{I_b Z} S + \frac{n}{2 I_b} \tag{4a}$$

Such plots for a few of the systems studied are given in Figure 42. In the case of other systems (as, for instance, D) the graphs showed a very definite curvature, and it must therefore be concluded that equation (4) is only a rough approximation in some cases.

If the empirical equation (4) really represented the facts over the whole range, then the intercept on the axis of S/V_m of the graphs of S/V_m vs. S should have the value of $\frac{n}{2\,I_b}$. This relation was found to obtain in many of the cases tested. In other cases V_m was 20 to 30 per cent less than this relation would indicate. This is presumably the result of an appreciable damping of the oscillation; still other cases showed values of V_m higher than the theoretical. These can only be accounted for by stating that in these generators the equation does not fit the facts closely enough to justify extrapolation to extremely low values of S.

The slope of the line obtained by plotting S/V_m vs. S has the value $\frac{n}{I_b Z}$ and hence the quotient of twice the intercept divided by the slope of the line equals Z, and should theoretically be equal to $n\,Z_m$ or $F\,Z_2$.

This relation was found to be only approximately true. The points marked by open circles in Figure 42 were located by using the value of $\frac{I_b}{n}$ obtained by the oscillograph and the value of Z_m obtained as the mean ratio of crest voltage to current at break at the lower speeds. In the cases plotted and in a few others the agreement between these two sets of data obtained from independent observations is quite satisfactory. On the other hand, in several cases the directly observed values of Z_m were nearly 60 per cent in excess of those deduced from the S/V_m vs. S lines. The disagreement in the intercept values in no case exceeded 30 per cent. In general, with any given system, a change such as adding capacitance in parallel with the secondary which decreases Z_2 is also found to decrease the slope of the S/V_m vs. S line but to leave its intercept unchanged. A change such as speed which changes I_b, is found to markedly change the intercept of the line, but to affect only slightly the quotient of slope to intercept.

The relation between crest voltage and capacitance added in parallel with the secondary is indicated by the equation

$$V_m = \frac{I_b}{n}\,F\sqrt{\frac{L_2}{C_o + C_a}} + E_r \qquad (5)$$

This is the same as equation (3) except that the total effective capacitance now consists of two parts, C_o, which represents that inherent in the spark generator; and C_a, which may be added in the form of the capacitance of the spark plug cables or of condensers. If E_r were zero and F a constant, then a plot of $\frac{1}{V_m^2}$ as ordinate against C_a as abscissa would yield a straight line. The intercept of this line on the axis of abscissæ would give C_o and the slope of the line would be $\frac{1}{F^2 I_b^2 L_2}$. Unfortunately, F varies when different condensers C_a are connected, because the frequencies of the resulting oscillations are changed. Also in most magnetos the E. M. F. of rotation E_r is not entirely negligible. It happens, however, that in all the systems tested the effects of F and E_r were such that the plot of $1/V_m^2$ vs. C_a was almost a straight line, though slightly convex upward. This empirical straight line relation can therefore be used with some assurance to predict the variation of V_m with C_a in other systems. (See figs. 20 to 30.) The intercept of the plotted lines, however, was in all but one case decidedly greater than the value of C_o obtained by other methods, and was often two or three times that value.

While the preceding discussion has shown certain relations between performance and other measurements on a given spark generator, a correlation of the performance data with the energy and current data given in columns 8 to 12 of Table 3, for the different generators, yields considerable additional information as regards two of the desirable properties of a spark generator, viz, (1) its ability to produce a reasonably high voltage on open circuit under adverse conditions, such as low speed when the plug is fouled with oil; and (2) its ability to fire a plug which is fouled with carbon. For the former property we may consider that the maximum secondary voltage developed at 50 R. P. M., as given in column 3 of Table 5, is representative. Combining this value with the total effective capacitance of the system (referred to the secondary side) which is given in column 7 of Table 4, we get the amount of energy (given in column 6 of Table 5) which the system actually has delivered into its capacitance at the instant of maximum voltage. Column 4, on the other hand, gives the energy which was apparently available at the instant of break, as indicated by the current determined by the oscillograph and the inductance determined by the flux meter. A comparison of columns 4 and 6 shows a very low efficiency as indicated by the figures in column 7, which are the quotients obtained by dividing the numbers in column 6 by those in column 4. These show that in one case less than one-tenth and in all but one case less than four-tenths of the energy originally at hand appears in the secondary at the time when it is most wanted to raise the voltage at the plug electrodes. If, however, the spark gap is so short that a spark can easily be produced, we find that the energy then delivered into it has the values [2] shown by the figures in column 5. Strangely enough these values are much greater than those in column 6 and thus show that there must be some process occurring while the voltage is building up which ties up much of the original energy in unavailable form, but which will release at least part of it later to be dissipated as heat in the spark gap. While rotational energy may account for some of the excess of column 5 over column 6 in the case of the magnetos, it can not do so in the battery systems, and it can not account for the great difference between column 4 and column 6 since it was not included in the computation of either energy value. An estimate of the possible energy losses in the resistance of the windings during the time the voltage is building up shows them to be negligible, and we must therefore attribute the low efficiency to some other cause. Eddy currents induced in the core, pole faces, and other parts of the magnetic circuit seem to be the principal cause of this poor performance.

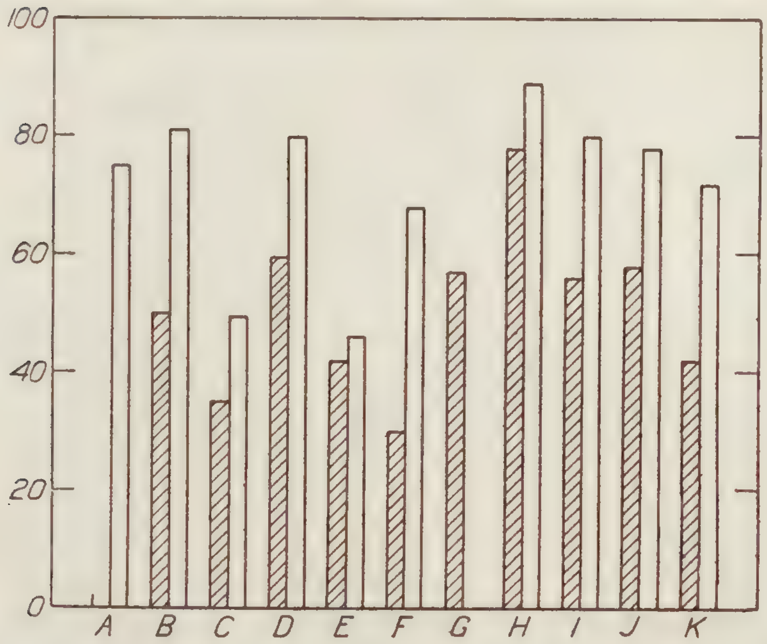


FIG. 43.—Diagram showing the observed and computed voltage efficiencies of the system when operating at 50 R. P. M. The 100 per cent line indicates the voltage to be expected if all the energy stored magnetically was used without losses to develop voltage. The heights of the shaded blocks indicate observed crest voltages in per cent of this value. The heights of the open blocks indicate the crest voltages computed on the assumption that the only losses present are those resulting from an eddy-current circuit such as would account for the measured inductance and resistance at 3,000 cycles

An independent and roughly quantitative estimate of the effects to be expected from eddy currents can be obtained from alternating-current bridge measurements, by a rather involved process which will be treated in another paper. From measurements of this kind made with 3,000-cycle alternating current, an estimate was made of the crest voltage to be expected with eddy currents flowing, as compared to that which would result in the absence of eddy currents. The results are shown by Figure 43. In this figure the heights of the shaded blocks show the actual crest voltage at 50 R. P. M. on a scale such that the 100 per cent line corresponds to the voltage which would be produced if all the energy available at the instant of "break" were effective in charging the capacitance of the system. The heights of the open blocks in Figure 43 show to the same scale the crest voltage computed theoretically from the alternating-current bridge measurements. It will be noted that the theoretical and actual departures from the ideal of 100 per cent are of the same order of magnitude. The departures from exact agreement can be accounted for, at least in part, by the fact that in actual operation the flux density in the magnetic circuit was much higher than could be used during the alternating-current measurements. Consequently the permeability was higher, and the eddy currents were of considerably greater relative magnitude. Any other source of energy loss, such, for example, as sparking at the breaker contacts would also tend to lower the actual voltage below the theoretical value.

For the second important property of a spark generator (i. e., ability to fire a plug which is fouled with a conducting carbon deposit), we may take 5,000 volts as a typical operating voltage and from the curves plotted in Figures 9 to 19 read off the greatest value of the shunting conductance or "utility" which may be connected in parallel with the spark plug without causing the generator to fail to produce this voltage. Values thus obtained are given in column 2 of Table 6, and column 3 gives the reciprocal of the utility, i. e., the lowest possible shunting resistance. Column 4 gives the product of the conductance by the assumed voltage (5,000 volts), and hence is the value of the current flowing through the secondary winding and the resistor at the instant of maximum voltage. A comparison of these values with those in column 5, which gives the quotient of primary current at break divided by the ratio of turns, shows the former to exceed the latter in all but two cases. Column 6 is the quotient of column 4 divided by column 5. The fact that the secondary ampere turns thus exceed, and are often nearly double, the initial primary ampere turns, indicates that at the instant of maximum secondary voltage the primary current has reversed its direction and tends to demagnetize the core, while the secondary current has risen to such a value as to neutralize the primary ampere-turns and, in addition, to maintain much of the original magnetic flux.

---

[2] These latter values were obtained by interpolation of the data plotted in figs. 40 and 41 on the assumption that the curves were straight line between the origin and the first plotted point. This assumption is, of course, not true but insures that the values given in column 5 are certainly less than the correct values.

Any actual spark generator presents such a complex electrical system as to defy a rigorous mathematical analysis of its performance. Certain simplified model circuits have been suggested which serve to imitate with more or less fidelity the principal features of the actual machine. (Reference 13.) Of these the simplest is the "single-coil model," which consists of a single inductance coil connected in parallel with a condenser and the breaker terminals. This model will account for the relations between crest voltage and current at break, and between crest voltage and shunting capacitance, which are discussed above. The "closed-coil model" adds to the single-coil model an extra circuit, the currents in which tend to simulate the eddy currents in the actual magneto. The open blocks in Figure 43 were computed by the use of this arrangement of circuits, and it would seem to be useful in connection with problems of design in which eddy-current effects are to be considered. Neither of these models, however, correctly represents the conditions of current flow described in the preceding paragraph, which occurs when the secondary terminals are heavily shunted. The more complex "double-coil model" must, therefore, be used in discussing these phenomena. This model consists of two inductively coupled circuits, each containing a coil and a condenser. A complete theory of this model has been worked out by Taylor-Jones (Reference 14), but the application of it is very laborious. For the case where a low resistance is connected across the secondary condenser it is possible to work out some rather simpler relations by making two simplifying assumptions. (Reference 6.) The first is that the secondary capacitance is absent. This assumption should not introduce serious errors for low values of shunting resistance, since the time required for currents to adjust themselves between the secondary capacitance and the resistance then becomes very short compared to the period of the other oscillations concerned. The second assumption is that the effective resistance of the primary winding is zero. This assumption is entirely justifiable as regards the resistance of the copper coil itself. It can not, however, be taken for certain a priori that the energy loss resulting from eddy currents is negligible under these conditions. However, the figures given in column 7 were computed on this assumption, and it will be noted that they do not differ very greatly from the observed values in column 4. The comparison of theory and observation in this respect is also shown by Figure 44. Here the open blocks show the

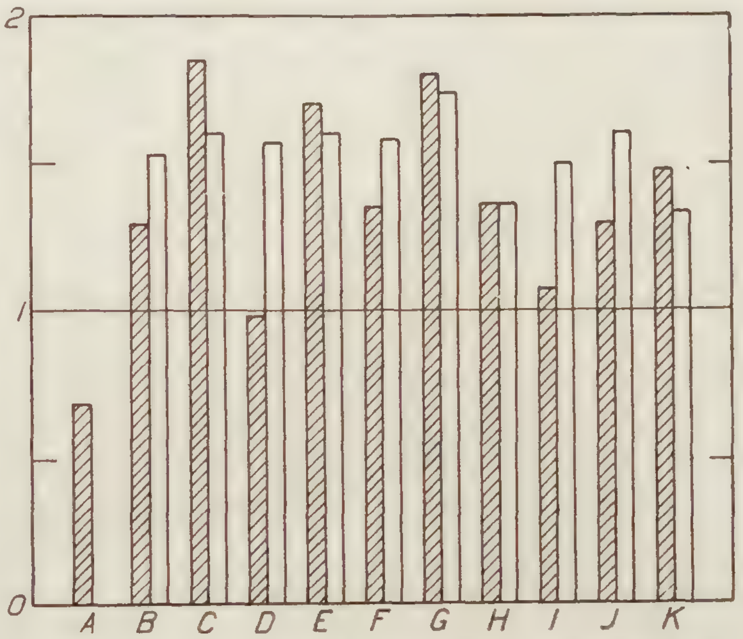


FIG. 44.—Diagram comparing the observed and computed crest values of current, with the current at break, when the systems are operating at 1,000 R. P. M. with a shunting resistance sufficient to reduce the crest voltage to 5,000 volts. The horizontal line marked "1" indicates the primary current at break referred to the secondary side. The heights of the shaded blocks indicate the observed crest values of secondary current expressed as fractions of the current at break. The heights of the open blocks indicate the same quantity as computed from the coupling, inductance, capacitance, and shunting resistance. The horizontal line marked "2" indicates the values to be expected if the primary current had reversed its direction without loss

theoretical performance (i. e., crest value of secondary current expressed in terms of the current at break), while the shaded blocks show the observed performance. The letters indicate the ignition system to which each pair of blocks corresponds. The horizontal line marked "1" indicates the value of current at break (referred to the secondary side), and it will be noted that in most cases the observed crest value rises to nearly double this amount. It will be seen that most of the observed values are less than the computed, and such departures can be readily attributed to the effect of eddy-current loss in increasing the effective primary resistance. These departures are relatively small and indicate that the effect of eddy currents is much less important on this property of a spark generator than it is on the open-circuit voltage. The abnormally high value observed with system C can only be attributed to experimental error.

An inspection of the values of total stored magnetic energy given in column 10 or of the heat per spark actually delivered, as given in column 12 of Table 3, shows a very noticeable difference between the values for the magnetos and for the battery systems. That this difference is not a fortuitous result of the particular systems selected for this study but is a necessary result of the relatively low voltage of the batteries available in battery ignition systems, can be seen from the following considerations. For a battery system supplying an engine at a given speed there is available a certain fixed time t_o (which can not be greater than the interval between sparks) in which to store magnetic energy. The current at break in such a system is

$$I_b=\frac{E}{R_1}\left(1-e^{\frac{-R_1 t_0}{L_1}}\right) \tag{6}$$

and the stored energy is

$$W_b=\frac{L_1 I_b^2}{2}=\frac{E^2 L_1}{2 R_1^2}\left(1-e^{\frac{-R_1 t_0}{L_1}}\right)^2 \tag{7}$$

For a coil of a given shape and size a change in the number of primary turns will change both R_1 and L_1 in the same ratio and leave the time constant $\frac{L_1}{R_1}$ unaffected. A change in the size of the entire structure, however, will both increase L_1 and decrease R_1. The energy may therefore conveniently be expressed in terms of the time constant $T=\frac{L_1}{R_1}$ as

$$W_b=\frac{E^2 T}{2 R_1}\left(1-e^{\frac{-t_0}{T}}\right)^2 \tag{8}$$

In this form it appears that as the size of the coil is increased the value of W_b will at first increase but that beyond a certain size the effect of the T in the exponent of the last term will more than offset the gain in the first factor. There is, therefore, for a given circuit resistance a certain best value of T, and hence a best size of coil which will store the greatest amount of energy. This best value of T is approximately equal to 0.79 t_o.

As the resistance is decreased the energy will increase in inverse proportion. However, the designer is limited by the fact that the breaker contact can reliably interrupt the current only if it is less than a certain fairly definite value, which we may call I_c, and which in practice seems to be less than 5 amperes. Since this value should not be exceeded even at low engine speeds, the resistance can not be made less than E/I_c, so that the maximum energy attainable at the full rated speed is

$$W_m=\frac{EI_c\, t_o\, 0.79}{2}\left(1-e^{-1.27}\right)^2 \tag{9}$$

$$=0.20\ EI_c\, t_o$$

and at slow speeds the energy is 0.394 $EI_c\, t_o$.

Considerations of convenience in the number of cells to be carried usually limits the battery voltage to 6 or 12 volts. A magneto, on the other hand, operating at normal speeds, may generate in its primary a crest voltage of about 100 volts, and hence can store 10 to 20 times as much energy during the interval between sparks.

SUMMARY AND CONCLUSIONS

In the work here reported the performance of a series of spark generators of various types has been studied under various conditions of operation and their electrical and magnetic characteristics have been determined.

Certain theoretical and empirical relationships were correlated with the measured properties, and it was found that these relationships can be made to serve a useful purpose in the analysis and comparison of the behavior of various types of spark generator under various conditions.

It would appear also that a careful consideration of the characteristics and performance data here presented in the light of certain simplified models should lead to improvements in design.

If one regards the problem of automotive ignition as a whole, it appears that at present the burden of operation is divided between the spark plug and the spark generator in such a way that the plug is required to maintain two conditions: First, the sparking voltage between its electrodes must lie in the range of from 1,000 to 8,000 volts. A voltage below the lower limit may give a spark too feeble for ignition and a voltage above the upper limit may not always be attainable by the spark generator. This requirement can be easily met by a plug of good design. Secondly, the shunting resistance in parallel with the spark gap must be greater than about 50,000 ohms. It is not at all easy to satisfy this second requirement under conditions of low temperature and closed throttle with a plug which also must not cause preignition when the engine is operating at full power. One may, therefore, conclude that any improvement in the design of spark generators which will directly or indirectly increase their "utility" and permit of operating a spark plug with a heavier carbon deposit than at present will, to the same extent, relieve the burden which has hitherto fallen upon the shoulders of the long-suffering spark plug.

Regarded solely from the point of view of the energy values involved, it appears that there is much room for improvement both (1) in the voltage developed with a clean plug at low speeds or low battery voltage; and (2) in the "utility" when operating with dirty plugs. In the former case the net unavoidable energy expenditure required to produce the observed voltage is in many cases only one-third to one-tenth of that initially stored in the magnetic system. In the latter case there is also required the additional amount of energy which is dissipated in the carbon layer from the instant when the secondary voltage starts to rise until it reaches the sparking voltage of the gap. The total energy requirement for a 5,000-volt gap shunted with the resistances given in column 3 of Table 6 is given in column 10 of Table 6 and is seen to be much smaller than the initial stored energy given in column 11.

The cause of this obvious ineffectiveness of spark generators of the types here studied is fundamentally the same in both cases. A parasitic circuit magnetically coupled to the primary circuit temporarily checks the flux changes and ties up in unavailable form much of the initial store of energy until the moment of maximum voltage has passed; only to release it later when it merely serves to overheat and disintegrate the spark-plug electrodes. When the plug is clean the parasitic circuit is in the body of the iron core and pole pieces of the magnetic circuit. When the plug is dirty the principal parasitic current flows through the secondary winding and the carbon deposit.

Several modifications of the conventional systems are in use which may considerably improve their electrical performance under certain conditions. Among these are the use of an auxiliary spark gap in series with the spark plug, the connection of a battery in series with the primary winding of a magneto, and the impulse starter. If a valid theoretical basis for ignition system design can be built up, then it should be possible to so shift the design as to transfer the benefit derived from any such modification, or from such changes as the use of finer laminations or of steels of higher resistivity, to the condition where the gain is most needed. The double-coil model of Armagnat (Reference 15) and Taylor-Jones (Reference 16) and the simpler but less complete single-coil and closed-coil models suggested by one of the present authors (Reference 17) are steps toward such a basic theory.

The present work has shown that, so far as the measurements here made are concerned, the single-coil model gives a substantially correct picture of the operation of the spark generator with the secondary circuit open. The factor F which is introduced to cover the various energy losses is found to range from 0.31 to 0.75 in the systems tested. The closed-coil model is doubtless a closer approximation to the actual condition of affairs and the data show that the insertion into the equations of this model of the values for the constants of the eddy current circuit determined by alternating-current bridge measurements gives a fair approximation to the observed results.

When the secondary circuit is closed through a shunting resistance of low value, however, the single-coil model ceases to represent the facts even qualitatively and recourse must be made to the more complex double-coil model. This latter can, however, in this case, be simplified materially by omitting the secondary condenser without leading to very wide departures from observed results. Observations on the crest value of the voltage across the primary winding also indicates that the double-coil model and not the single-coil model should be used in considering problems such as the voltage stress imposed on the primary condenser and the contact points.

The connection between these models and the actual spark generators as regards details of design such as numbers of turns, core dimensions, etc., are not covered by the program of measurements here presented and must await the results of further work on specially constructed systems in which only one design constant is varied at a time.

NOTATION

a = fraction of time breaker contacts are closed.
C = capacitance.
C_a = capacitance added in parallel with the secondary.
C_g = capacitance from ground terminal of winding to frame.
C_w = capacitance distributed through layers of the secondary winding.
C_o = total effective capacitance of system under normal conditions referred to the secondary.
C_1 = capacitance of primary condenser.
E = voltage of battery.
E_r = E. M. F. of rotation.
$e = 2.718$ = base of Napierian logarithms.
F = factor by which crest voltage is reduced as a result of eddy current and resistance losses between instants of break and of crest voltage.
I = current.
I_b = current in primary at instant of break.
I_c = greatest value of current which contacts can break satisfactorily.
$I_o = \frac{E}{P}$ = final steady value of current in battery-coil system.
$k^2 = \frac{M^2}{L_1 L_2}$ = coefficient of coupling between primary and secondary circuits.
k^2_e = coefficient of coupling between eddy-current circuit and winding (in the closed-coil model).
L = self-inductance.
L_1 = inductance of primary winding.
L_2 = inductance of secondary winding.
M = mutual inductance.
n = effective turn ratio.
R_1 = resistance of primary circuit.

S = resistance of leakage path shunting the secondary.

$T = \frac{L_1}{R_1}$ = time constant of primary winding.

T_e = time constant of eddy current circuit.

t = time.

t_o = time interval between successive sparks.

V_m = crest value of voltage at secondary.

W = energy in spark.

W_b = stored magnetic energy at instant of break.

W_m = maximum value of W_b.

Z = empirical constant in equation 4 which has the physical dimensions of a resistance.

$Z_m = \frac{V_m}{I_b}$ = "impulsive impedance."

$Z_2 = \sqrt{\frac{L_2}{C_o}} = \frac{nZ_m}{F}$ = theoretical impulsive impedance referred to the secondary.

REFERENCES

1. C. C. Paterson and N. R. Campbell: Some Characteristics of the Spark Discharge and Its Effects in Igniting Explosive Mixtures. Physical Soc. Proc. (London), 31, p. 168; 1919.
2. D. W. Randolph and F. B. Silsbee: Flame Speed and Spark Intensity. N. A. C. A. Technical Report No. 187; 1924.
3. G. B. Upton: Spark Advance. Automotive Industries, 49, pp. 14 and 76; 1923.
4. F. B. Silsbee: The Sparking Voltage of Spark Plugs. N. A. C. A. Technical Report No. 202; 1925.
5. C. H. Sharp and E. D. Doyle: Trans. A. I. E. E., 35, p. 99; 1916. C. C. Paterson and N. R. Campbell: Phil. Mag., 37, p. 301; 1919.
6. F. B. Silsbee and D. W. Randolph: The Linkage Current Diagram for Representing Magneto Performance. Bureau of Standards Scientific Paper in preparation. (Containing the details of this method and a more complete discussion of the results.)
7. F. B. Silsbee, L. B. Loeb, and E. L. Fonseca: Heat Energy of Various Ignition Sparks. N. A. C. A. Technical Report No. 56; 1920. (Containing a detailed description of the method used.)
8. F. B. Silsbee: Characteristics of High-Tension Magnetos: Part II. N. A. C. A. Technical Report No. 58; 1920.
9. F. B. Silsbee: The Mathematical Theory of Induced Voltage in the High-Tension Magneto. Bureau of Standards Scientific Paper No. 424; 1921. (See p. 457 for details of this method.)
10. F. B. Silsbee: Scientific Paper No. 424, p. 452. Bureau of Standards; 1921.
11. F. B. Silsbee: Scientific Paper No. 424, p. 427, equation 27. Bureau of Standards; 1921.
12. F. B. Silsbee: Simplified Theory of the Magneto. N. A. C. A. Technical Report No. 123; 1921. Scientific Paper No. 424, pp. 426–437. Bureau of Standards; 1921.
13. F. B. Silsbee: Scientific Paper No. 424; Sections II and III. Bureau of Standards; 1921.
14. Taylor–Jones, E.: Phil. Mag., 36, p. 145; 1919.
15. H. Armagnat: Revue Electrique, 23, p. 321; 1915.
16. Taylor–Jones, E.: Phil. Mag. 36, p. 145; 1918.
17. F. B. Silsbee: Scientific Paper No. 424; Sections II and III. Bureau of Standards; 1921.

TABLE 1

MECHANICAL AND MISCELLANEOUS CHARACTERISTICS

1 System	2 Number of cylinders	3 Flux changes per revolution	4 Sparks per revolution	5 Angle on cam that breaker is closed	6 Angle on cam that breaker is open	7 Percentage of time that breaker is closed	8 Timing range (on engine crankshaft)	9 Angle from zero flux to break at full advance	10 Primary emf due to rotation at 1,000 R. P. M. effective value	11 Primary emf due to rotation at 1,000 R. P. M. crest value	12 Crest factor of emf of rotation
				Degrees	*Degrees*		*Degrees*	*Degrees*	*Volts*	*Volts*	
A—inductor	8	4	4	50	40	55	0	30	12.8	32	2.5
B—inductor	6 or 12	4	2 or 4	60	30 or 120	67 or 33	30	10	17.0	59	3.5
C—shuttle	4	2	2	154	26	85	34	12	12.4	49	4.0
D—revolving magnet	4	2	2	105	75	58	35	20	6.2	25	4.0
E—sleeve	8	4	4	30	60	33	0	21 or 10	8.8	30	3.4
F—inductor	4	4	2	58	122	32	30	7	18.0	46	2.5
G—pulsating flux	4	4	2	56	124	31	30	20	9.5	21	2.2
H—6-volt coil	8	[1] 8	8	30	15	67	-----	-----	-----	-----	-----
I—6-volt coil	4	[1] 4	4	45	45	50	-----	-----	-----	-----	-----
J—12-volt coil	4	[1] 4	4	45	45	50	-----	-----	-----	-----	-----
K—shuttle	4	2	2	150	30	17	35	5	(2)	(2)	(2)

[1] Per revolution of cam.

[2] Not measured.

TABLE 2

WINDING CHARACTERISTICS

1 System	2 Primary turns	3 Secondary turns	4 Effective ratio of turns n	5 Coupling coefficient $k^2=M^2/L_1L_2$	6 Leakage coefficient $1-k^2$	7 Resistance of primary winding at 20° C.	8 Resistance of secondary winding at 20° C.	9 Inductance of secondary winding at advance measured ballistically for high [4] speeds	10 Inductance of secondary winding at advance measured ballistically for low [5] speeds
						Ohms	*Ohms*	*Henrys*	*Henrys*
A—inductor	300	13,500	44.9	0.936	0.064	0.77	4,130	(1)	(1)
B—inductor	300	10,200	34.0	.936	.064	.72	1,850	55.6	50.0
C—shuttle	210	7,800	37.2	.961	.039	.67	2,350	53.2	52.5
D—revolving magnet	160	12,300	77.0	.932	.068	.30	8,540	132.0	122.0
E—sleeve	140	9,500	68.4	.972	.028	.51	1,960	84.6	82.0
F—inductor	[3] 234	9,400	40.2	.966	.034	.48	2,660	69.8	68.0
G—pulsating flux	[3] 211	13,500	64.1	.954	.046	.64	3,880	109.0	128.2
H—6-volt coil	240	13,600	56.6	.825	.175	.96	1,720	15.9	15.9
I—6-volt coil	145	11,300	78.2	.922	.078	1.04	4,270	39.8	39.8
J—12-volt coil	[3] 325	10,900	33.6	.940	.060	2.50	3,900	36.2	36.2
K—shuttle	130	9,900	76.1	.996	.004	.50	2,730	72.2	76.1

1 System	11 Inductance of secondary winding at advance measured with low-frequency alternating current	12 Inductance of secondary winding at advance measured at 3,000 cycles	13 Resistance of secondary winding at advance measured at 3,000 cycles	14 Impulsive impedance referred to secondary $Z_2=\sqrt{L_2/Co}$ computed for 50 R. P. M. assuming no losses	15 Impulsive impedance referred to secondary $nZ_m=nV_m/I_b$ mean of values observed at low speeds	16 Ratio of columns 15 to 14 $F=\frac{nZ_m}{Z_2}$	17 Frequency of main oscillation based on inductance given in column 10	18 Time-constant of primary circuit
	Henrys	*Henrys*	*Ohms*	*Ohms*	*Ohms*		*Cycles per second*	*Second*
A—inductor	30.0	17.0	115,000	-----	-----	-----	-----	-----
B—inductor	18.0	13.0	81,000	500,000	250,000	0.50	1,500	-----
C—shuttle	22.0	9.3	148,000	470,000	170,000	.37	1,410	-----
D—revolving magnet	43.0	[2] 26.0	[2] 76,500	880,000	440,000	.50	1,100	-----
E—sleeve	37.0	[2] 11.0	[2] 304,000	840,000	350,000	.42	1,590	-----
F—inductor	33.5	15.0	170,000	580,000	180,000	.31	1,350	-----
G—pulsating flux	(1)	(1)	(1)	900,000	490,000	.54	1,220	-----
H—6-volt coil	15.6	14.5	45,500	330,000	250,000	.75	3,330	0.0040
I—6-volt coil	32.0	21.0	132,000	540,000	260,000	.48	2,130	.0053
J—12-volt coil	29.5	19.0	109,000	340,000	220,000	.64	1,510	.0071
K—shuttle	37.0	20.0	175,000	720,000	270,000	.37	1,550	-----

[1] Not measured.

[2] At 2,500 cycles per second.

[3] Data supplied by maker.

[4] For value of current equal to that observed at break at 2,000 sparks per minute.

[5] For value of current equal to that observed at break at 50 R. P. M.

TABLE 3

MAGNETIC CHARACTERISTICS

1 System	2 Maximum change in primary flux turns	3 Maximum flux through core	4 Weight of magnets	5 Cross-section of magnets	6 Length of magnet	7 Density of useful flux in magnet	8 Maximum possible current	9 Maximum possible energy per spark	10 Stored magnetic energy at break 2,000 sparks per minute at advance	11 Stored magnetic energy at break 50 R. P. M. at advance	12 Maximum observed heat per spark at advance
	Maxwell-turns	*Maxwells*	*Kilograms*	*Cm.*[2]	*Centimeters*	*Gausses*	*Amperes*	*Joule*	*Joule*	*Joule*	*Joule*
A—inductor	11.6 x 10^6	19,300	1.33	5.6	28.0	3,400	(1)	(1)	(1)	(1)	0.048
B—inductor	13.3	22,200	2.44	11.2	26.4	2,000	3.0	0.185	0.150	0.026	.130
C—shuttle	21.1	50,000	2.24	7.8	34.0	6,400	6.3	.650	.210	.061	.180
D—revolving magnet	9.0	28,000	1.14	7.5	16.0	3,700	5.0	.226	.114	.017	.076
E—sleeve	8.0	28,600	1.98	7.0	33.5	4,100	5.7	.228	.071	.020	.066
F—inductor	19.0	40,500	2.08	10.6	23.8	3,800	4.3	.420	.257	.086	.162
G—pulsating flux	9.6	45,500	1.35	8.9	18.3	5,100	5.9	.280	[3] .106	.010	.096
H—6-volt coil	1.9	7,900	----------	[2] 1.77	[2] 9.0	----------	3.8	.036	.036	.036	.029
I—6-volt coil	3.3	22,800	----------	[2] 6.7	----------	----------	5.0	.082	.072	.082	.033
J—12-volt coil	7.6	23,400	----------	[2] 6.7	----------	----------	2.4	.091	.069	.091	.037
K—shuttle	10.0	38,500	1.89	6.8	33.4	5,700	10.0	.520	.095	.017	(1)

[1] Not determined.

[2] Dimensions of core.

[3] At retard.

TABLE 4

CAPACITANCE DATA

1 System	2 Capacitance of primary condenser C_1	3 Capacitance of primary condenser referred to secondary C_1/n^2	4 Capacitance between core and inner layer of winding C_g	5 Internal capacitance among layers of windings C_w	6 Terminal capacitance between outer layer and frame C_t	7 Total effective capacitance referred to secondary C_e
	Microfarad	*Micro-micro farads*	*Micro-micro farads*	*Micro-micro farads*	*Micro-micro farads*	*Micro-micro farads*
A—inductor	0.060	30	250	100	[3] 15	180
B—inductor	.098	85	290	75	[3] 16	200
C—shuttle	.230	166	(5)	[2] 50	[1] 25	260
D—revolving magnet	(5)	(5)	(5)	75	[3] 31	[4] 160
E—sleeve	.21	45	(5)	35	[1] 25	120
F—inductor	.19	118	280	50	[3] 17	200
G—pulsating flux	.16	39	130	60	[3] 42	160
H—6-volt coil	.26	81	110	40	[3] 4	140
I—6-volt coil	.24	39	30	50	[3] 29	140
J—12-volt coil	.24	213	50	50	[3] 29	310
K—shuttle	.13	22	230	60	[3] 48	150

[1] Estimated from dimensions.

[2] From assumed C_t and observed $(C_w + C_t)$ at radio frequency.

[3] From audio frequency bridge.

[4] Estimated.

[5] Inaccessible

TABLE 5

DATA ON ENERGY VALUES AT LOW SPEEDS

1 System	2 Primary current at break at 50 R. P. M. at advance	3 Secondary crest voltage at 50 R. P. M. at advance	4 Stored magnetic energy at break at 50 R. P. M. at advance	5 Heat per spark at 50 R. P. M. at advance (estimated from data at high speed)	6 Crest value of electrostatic energy at 50 R. P. M. at advance	7 Energy efficiency as a coil $\frac{C_0 V_m^2}{2W}$	8 Time-constant of eddy circuit at 3,000 cycles (T_e)	9 Coefficient of coupling between coils and eddy circuit at 3,000 cycles (k_e^2)	10 Theoretical voltage efficiency using constants observed at 3,000 cycles	11 Observed voltage efficiency at 50 R. P. M. at advance
	Amperes	*Volts*	*Joule*	*Joule*	*Joule*		*Second*			
A—inductor	0.52	7,000	(1)	0.013	0.0044	---------	0.000119	0.53	0.75	---------
B—inductor	1.10	8,000	0.026	.013	.0064	0.25	.000067	.48	.81	0.50
C—shuttle	1.80	8,600	.061	.011	.0074	.12	.000086	.85	.49	.35
D—revolving magnet	1.30	8,600	.017	.007	.0059	.35	[2] .000240	[2] .41	[2] .80	.59
E—sleeve	1.50	8,000	.020	.006	.0037	.18	[2] .000130	[2] .91	[2] .46	.42
F—inductor	2.05	9,000	.086	.012	.0081	.09	.000105	.67	.68	.30
G—pulsating flux	.80	6,500	.010	.008	.0033	.33	(1)	(1)	(1)	.57
H—6-volt coil	3.80	17,700	.036	.029	.0220	.61	.000023	.40	.89	.78
I—6-volt coil	4.96	15,900	.082	.033	.0250	.31	.000083	.47	.80	.56
J—12-volt coil	2.38	14,200	.091	.036	.0310	.34	.000098	.51	.78	.58
K—shuttle	1.60	6,500	.017	(1)	.0031	.18	.000100	.59	.72	.42

[1] Not measured.

[2] At 2,500 cycles per second.

TABLE 6

DATA ON OPERATION WITH SHUNTING CONDUCTANCE

1 System	2 Conductance (*1/S*) for 5,000 volts at 2,000 sparks per minute at advance	3 Shunting resistance (*S*) for 5,000 volts at 2,000 sparks per minute at advance	4 Crest value of current through shunting resistance at 2,000 sparks per minute computed from observed voltage	5 Current at break at 2,000 sparks per minute at advance referred to secondary I_b/n	6 Quotient of columns 4 and 5	7 Crest value of current through shunting resistance at 2,000 sparks per minute computed by double-coil model from current at break	8 Energy lost in shunting resistance during rise of voltage [1]	9 Crest value of electrostatic energy at 5,000 volts	10 Total energy required per spark at 5,000 volts with conductance given in column 2	11 Stored magnetic energy at break at 2,000 sparks per minute at advance
	Micromhos	*Ohms*	*Ampere*	*Ampere*		*Ampere*	*Joule*	*Joule*	*Joule*	*Joule*
A—inductor	5	200,000	0.025	0.037	0.68	---------	---------	0.0022	---------	(2)
B—inductor	19	53,000	.094	.073	1.29	0.112	.040	.0025	0.043	0.150
C—shuttle	33	30,000	.165	.089	1.85	.142	.073	.0032	.076	.209
D—revolving magnet	8	125,000	.040	.041	.98	.064	.023	.0020	.025	.114
E—sleeve	14	71,000	.070	.041	1.70	.066	.027	.0015	.029	.071
F—inductor	23	43,000	.116	.086	1.35	.136	.053	.0025	.026	.257
G—pulsating flux	[3] 20	[3] 50,000	[3] .100	[3] .056	[3] 1.80	[3] .098	[3] .051	[3] .0020	[3] .053	[3] .106
H—6-volt coil	18	55,000	.091	.067	1.36	.091	.017	.0018	.019	.036
I—6-volt coil	13	78,000	.064	.060	1.07	.090	.019	.0017	.021	.072
J—12-volt coil	16	67,000	.080	.062	1.29	.099	.033	.0038	.037	.069
K—shuttle	15	67,000	.075	.051	1.47	.068	.030	.0018	.032	.095

[1] Assuming frequency given in column 17, Table 2.

[2] Not measured.

[3] At retard.

REPORT No. 242

CHARACTERISTICS OF A TWIN-FLOAT SEAPLANE DURING TAKE-OFF

By JOHN W. CROWLEY, Jr., and K. M. RONAN
Langley Memorial Aeronautical Laboratory

REPORT No. 242

CHARACTERISTICS OF A TWIN-FLOAT SEAPLANE DURING TAKE-OFF

By John W. Crowley, Jr., and K. M. Ronan

SUMMARY

At the request of the Bureau of Aeronautics, Navy Department, an investigation has been made, by the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics, of the planing and get-away characteristics of three representative types of seaplanes, namely: Single float, boat, and twin float. The experiments carried out on the single float (Reference 1) and boat (Reference 2) types have been reported on previously. This report covers the investigation conducted on the twin-float seaplane, the DT–2, and includes, as an appendix, a brief summary of the results obtained on all three tests.

The fundamental take-off characteristics of the DT–2 seaplane (twin float) are similar to those of the N–9H (single float) and the F–5L (boat type). At low water speeds, 20 to 25 M. P. H., the seaplane trims by the stern and has a high resistance. Above these speeds the longitudinal control becomes increasingly effective until, with a gross load of 6,000 pounds, it is possible to get away at angles of attack of 8 to 14 degrees with corresponding speeds of 56 to 46 M.P.H. It was further determined that an increase in the load caused little if any change in the water speed at which the maximum angle and resistance occurred, but that it did produce an increase in the maximum angle.

INTRODUCTION

The use of twin floats has been mainly restricted to racing and torpedo-carrying seaplanes. The float characteristics of the former, beyond stability and aerodynamic resistance, are of small consequence as an abundance of reserve power is available for getting off. Since the requirement of the torpedo seaplane is to get off with a maximum load, it was selected as being the most representative of twin-float types to test. The difference in the type and size of the seaplane proper would probably affect the over-all take-off performance to a greater extent than would the use of twin floats in place of a single float. It is therefore expected that the difference between the single and twin float results is more of a type than a float effect. The tests have been conducted mainly to acquaint the designer and those who test model floats with the actual conditions arising from the beginning of the take-off[1] to the get-away.[2] The report also contains information which is interesting and valuable to pilots.

METHODS AND APPARATUS

The seaplane used was the Douglas torpedo plane, the DT–2.[3] The floats and fabric were in fairly good condition, but the engine was in need of an overhaul and the propeller used held it down to 1,550 R. P. M. at the get-away.

As in the tests on the other types of seaplanes, four control methods, covering practically all the possible control variations, were used, namely: Free, forward, back, and normal. The control forward and control back methods are self-explanatory, but the other two may need some further description. In the control-free method the pilot allows the elevators to float but maintains enough control to prevent excessive oscillations and at the same time maintains proper lateral balance and directional control by means of the ailerons and rudder. The piloting was done entirely by Mr. Paul King, of the laboratory staff, so that all the normal take-offs should be quite similar. The following is his description of the normal take-off:

---

[1] Take-off as used herein is the period on the water from the time of the opening of the throttle until the seaplane leaves the water.

[2] Get-away as used herein is the act of leaving the water.

[3] See Appendix 1.

"The take-off of this seaplane, light, was very easy. At the opening of the throttle the control column was pulled well back. As the seaplane gained in speed the control column was eased foward slightly past neutral, thus allowing it to get on the step. At a speed of approximately 55 M. P. H. a slight backward pressure was exerted on the control column, enabling the seaplane to fly off the water. It was unnecessary to pull the DT–2 off. With the heavier loading the procedure differed but slightly. To get it upon the step it was necessary to throw the seaplane by pushing the control column smartly forward just past neutral. After getting upon the step the column was returned to neutral and held there until sufficient speed was attained; then by a sharp backward pull the seaplane left the water. In several instances, with the heavy load, as the DT–2 was thrown upon the step there was a tendency for it to porpoise. This was stopped by pulling the control column backward as the seaplane pitched forward, and pushing forward as it reared backward. At no time was it necessary to rock the seaplane to get upon the step, nor was the stabilizer setting changed, it being set at all times for level flying at cruising speed."

To facilitate the testing, the runs to obtain the effect of these control variations were made with a gross light load (6,000 pounds). To ascertain the effect of different loadings and to obtain the full-load conditions one take-off was made with a load of 6,800 pounds and one with a load of 7,500 pounds. The loading was obtained by filling the distance fuel tanks with water and attaching them in place of the torpedo.

Continuous synchronized records of the air speed, water speed, and planing angle were obtained from the beginning to the end of the take-off.

The air speed was measured by means of a Baden double-Venturi head mounted on a boom extending a chord length ahead of the wings, and an N. A. C. A. air-speed recorder. (Reference 3.)

The water speed was measured by a Pitot tube, extended through a breather hole, and connected to an instrument similar in principle to the air-speed recorder. The tube was attached so that it could be lowered into place after the seaplane was launched. A comparison of runs with and without the Pitot tube lowered showed that its resistance was negligible. A calibration of the attachment on a water-speed course showed the indicated water speed to be slightly high at low speeds. The necessary correction has been applied to the curves.

The planing angle was obtained by means of a vane mounted on a boom a chord length ahead of the wings, and free to align itself along the relative wind. Integral with the vane was a variable resistance so connected with a recording galvanometer (Reference 4) in a Wheatstone bridge circuit that any deflection of the vane was recorded by the galvanometer. A calibration to obtain the true angle, which differs from the indicated by the "upwash" angle, was made by mounting a gun camera parallel to the *Y*-axis of the seaplane so as to take pictures of the horizon during a take-off. These pictures gave the inclination of the seaplane to the horizontal, and therefore the planing angle, at the same time that a record was taken of the indicated angle. The calibration thus obtained was extended to cover all the flights by asssuming that the variation is a function of the angle of attack only.

PRECISION

The estimated precision is as follows:

Air speed	±1 M. P. H.
Water speed	±1 M. P. H.
Angles	±1°.
Time synchronization	±0.5 sec.

DISCUSSION OF RESULTS

The take-off may be divided into three stages—plowing, transition, and planing, where the term "transition" is used to denote the period during which the float is climbing out of the water from the condition where the lift is almost entirely buoyant (plowing) to where it becomes dynamic (planing). These stages are ordinarily well defined by the slope of the velocity curves and the change of trim. However, on the light load runs the resistance is practically constant throughout so that it is difficult to pick out the boundaries from the velocity curves, but they have been established approximately from the angle curves and are noted as "rising to step" and "planing on step."

The results are given in curve form in Figures 1 to 17. Figures 1 to 15 show curves of the original take-offs and Figures 16 and 17 are derived from them.

The take-off by the control-free method, which allows the seaplane to trim naturally, is shown in Figures 1 to 3. In these figures it will be noted that the slopes of the water-speed curves are nearly constant up to a water speed of approximately 37 M. P. H., where they commence to flatten out, indicating an increase in resistance. The curves also establish the fact that the normal planing angle of this seaplane is about 4°. The seaplane appears to pass through the transition stage quickly and without any tendency to oscillate, but once on the step it oscillates steadily until water speeds of 40 M. P. H. are reached, beyond which the seaplane becomes more stable. This characteristic is particularly noticeable in Figure 3, which shows the results of a run made on water with a glassy surface. The increased stability at high speeds is unusual because oscillations or even porpoising are quite apt to occur at the higher speeds, particularly when light float loadings are used. (Reference 5.) While the control-free method will allow a take-off on the DT–2, it is objectionable because control is needed to damp oscillations when they occur.

It seems worth stating at this time that the above-mentioned increase in resistance at high speeds was characteristic of the boat-type seaplane, the F–5L, but not of the single-float seaplane, the N–9H. The N–9H type of float is similar to those used on the DT–2 except that the former has a V bottom with a 7½° slope while the latter have 15° V bottoms. The interference effects of the floats are not appreciable when planing, since the bow wave is small, so that part of the difference in resistance between the single and double float types at high planing speeds is due to the difference in the angles of the V bottoms.

Figures 4 and 5 show the records of take-offs made by holding the elevators down (control forward). The curves are quite similar to those of the control-free method except that this method has largely eliminated the trimming aft during the transition stage. This effect would be reduced by a larger load because the float moments would be increased. Here again the slope of the water-speed curves is nearly constant up to 37 M. P. H., where it flattens out, and here also planing oscillations are very evident, being even more pronounced than with the control-free method. A run taken on smooth water (fig. 5) shows especially noticeable oscillations in which the period is constant at 1¼ seconds and the amplitude is 3°. As shown here, the attempt to hold the nose of a seaplane lower than its natural trim seems to produce oscillations which may lead to severe porpoising. In a normal take-off it is quite usual for a pilot to ease forward on the control, after planing is started, to allow the seaplane to pick up speed. This usually gives the desired results, but on the DT–2 it would intensify the oscillating tendency, which is detrimental to the life of the seaplane.

Figures 6, 7, and 8 show runs made with the elevators held up throughout. The trimming effectiveness of this control is manifested by the increased transition stage angles and the greatly increased planing angles over those obtained with free control. As is shown by a comparison of the slopes of the water-speed curves of the different methods, these high planing angles (10° or more) are detrimental in that they increase the resistance at low planing speeds. The characteristic qualities of more or less steady planing on rippled water (fig. 6) and oscillatory planing on smooth water (figs. 7 and 8) show that the stability is neither noticeably improved nor harmed by this control.

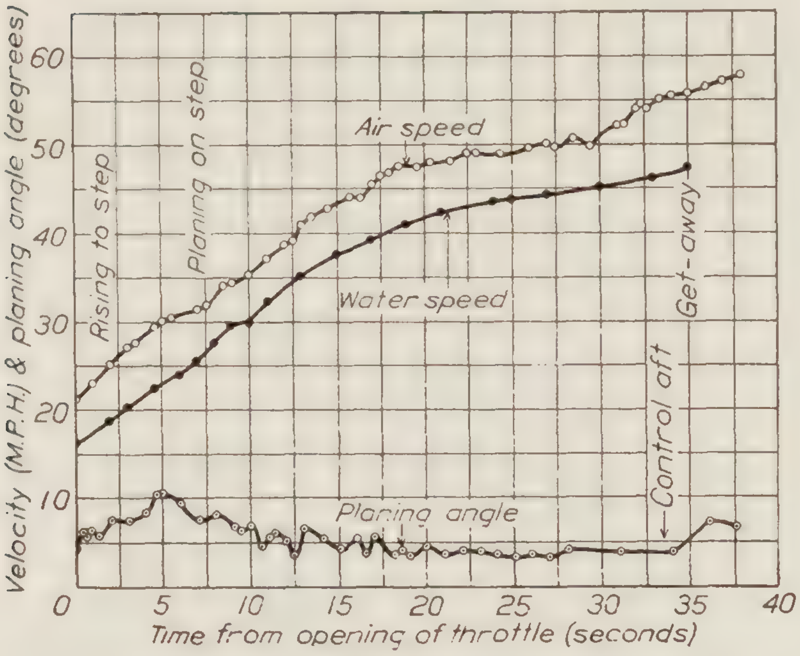


FIG. 1.—Method: Control free. Weight, 6,000 pounds. Rippled water

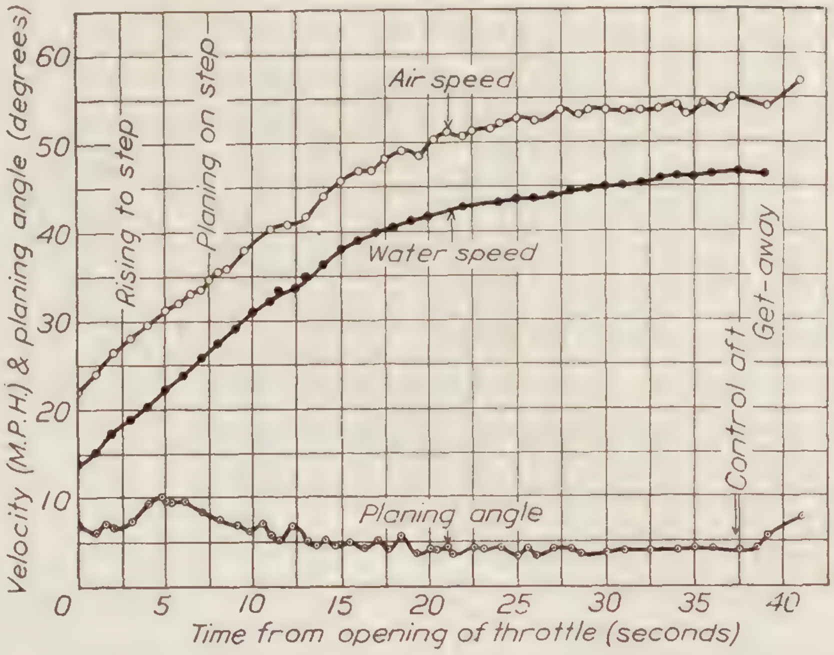


FIG. 2.—Method: Control free. Weight, 6,000 pounds. Rippled water

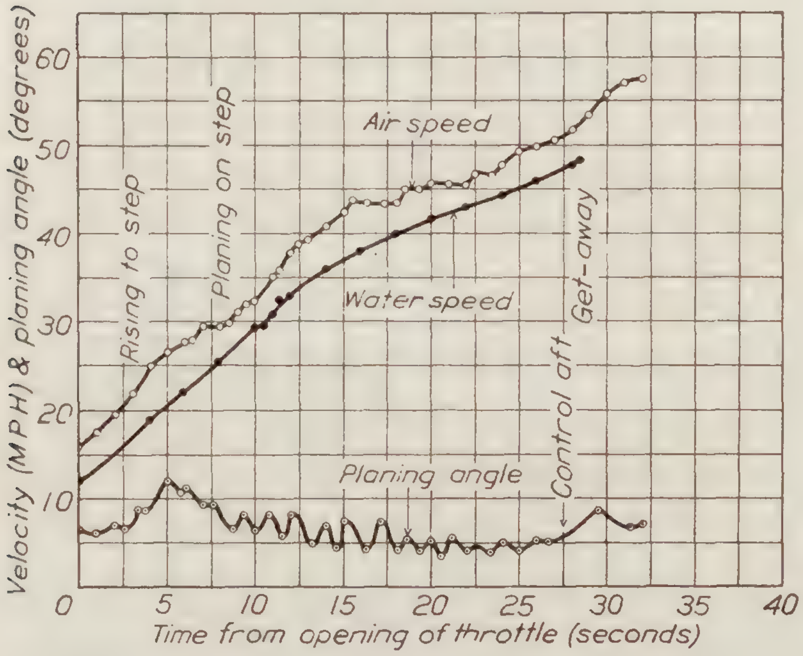


FIG. 3.—Method: Control free. Weight, 6,000 pounds. Smooth water

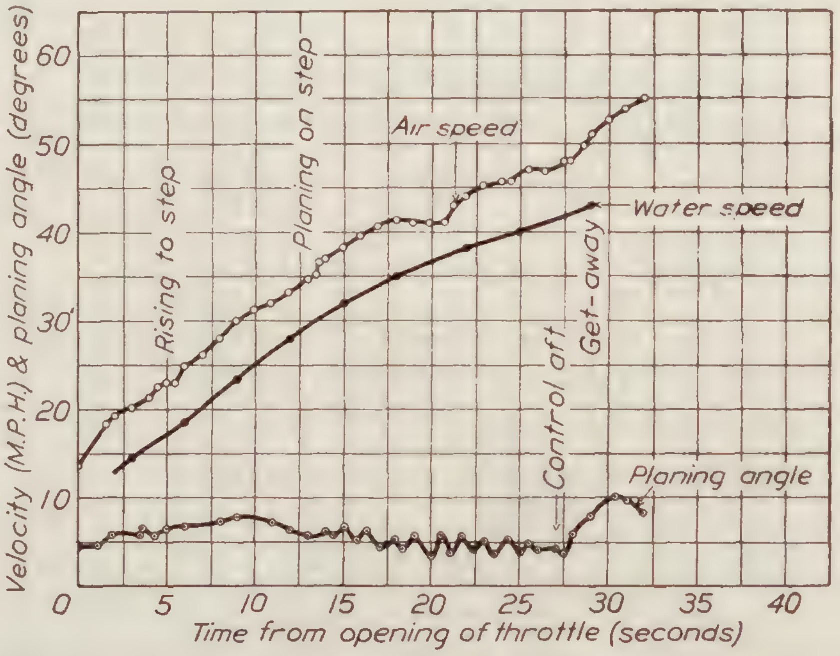


FIG. 4.—Method: Control forward. Weight, 6,000 pounds. Rippled water

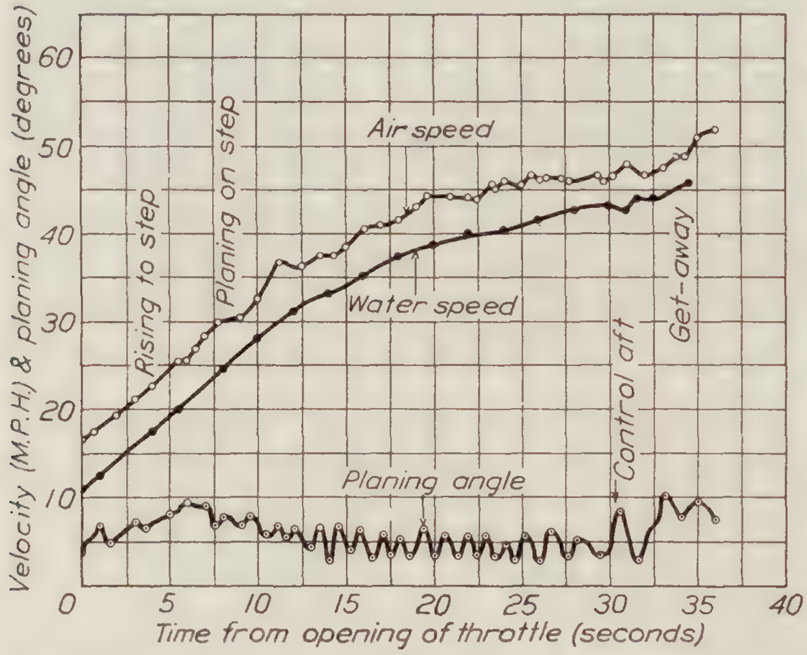


FIG. 5.—Method: Control forward. Weight, 6,000 pounds. Smooth water

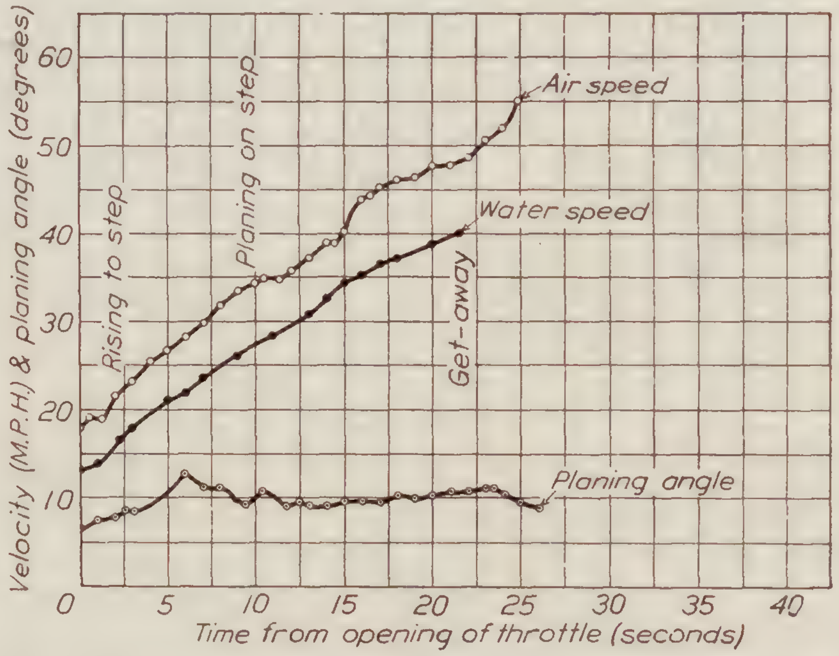


FIG. 6.—Method: Control back. Weight, 6,000 pounds. Rippled water

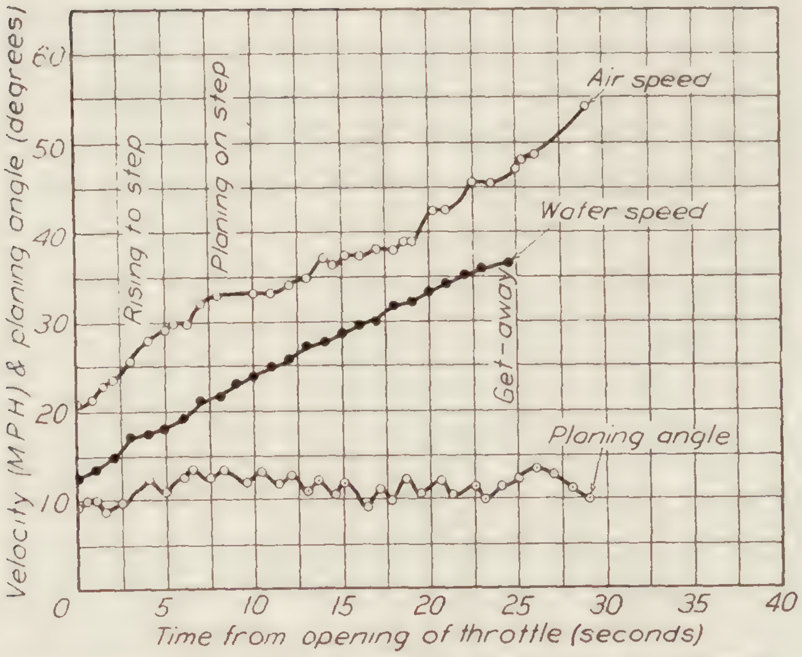


FIG. 7.—Method: Control back. Weight, 6,000 pounds. Smooth water

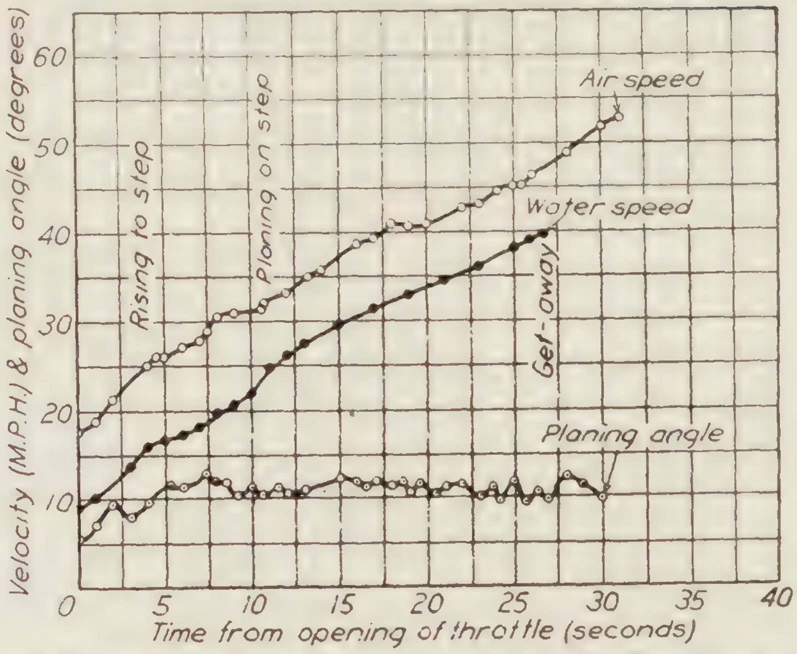


FIG. 8.—Method: Control back. Weight, 6,000 pounds. Smooth water

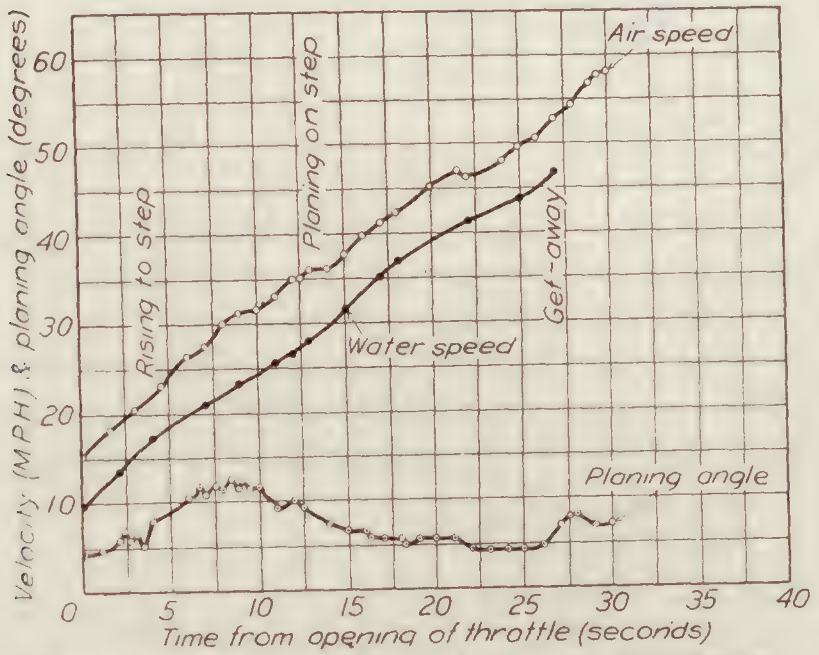


FIG. 9.—Method: Normal. Weight, 6,000 pounds. Rippled water

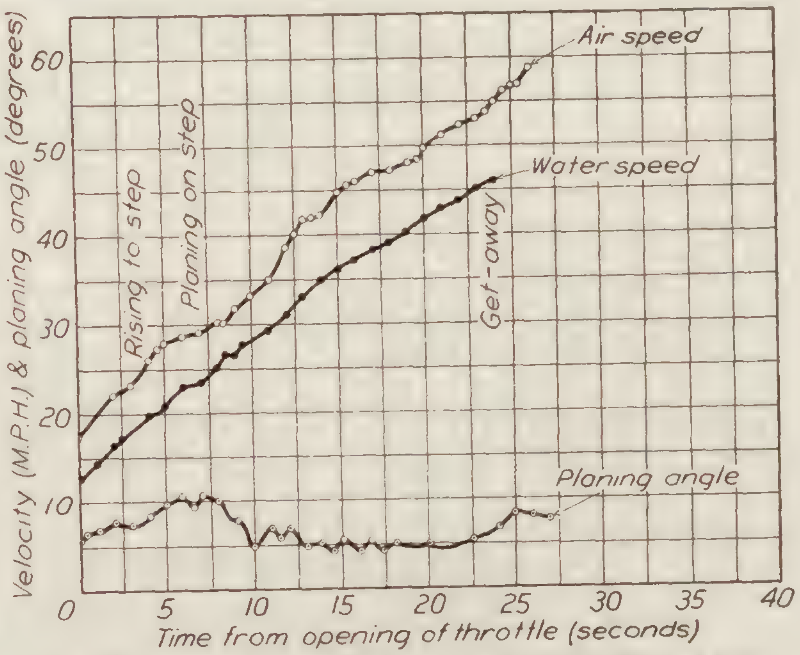


FIG. 10.—Method: Normal. Weight, 6,000 pounds. Rippled water

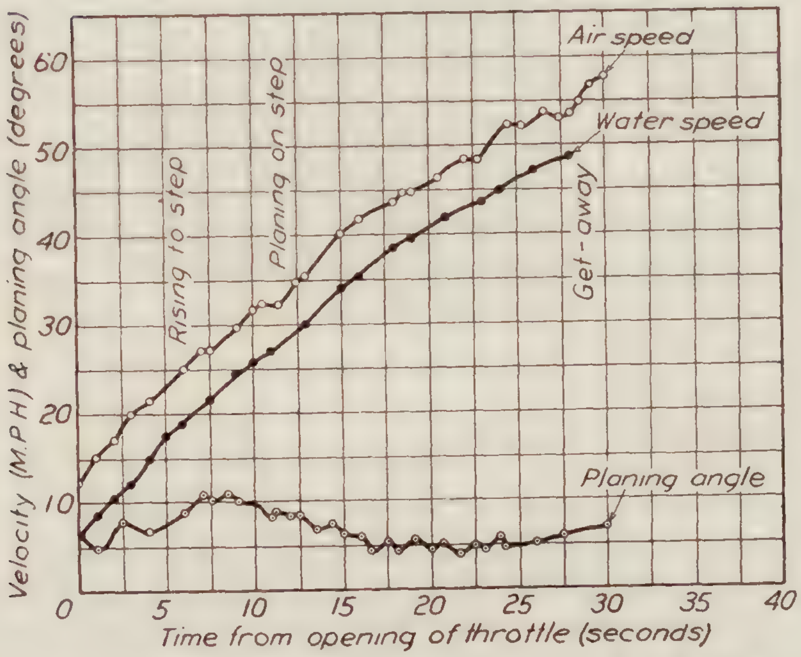


FIG. 11.—Method: Normal. Weight, 6,000 pounds. Smooth water

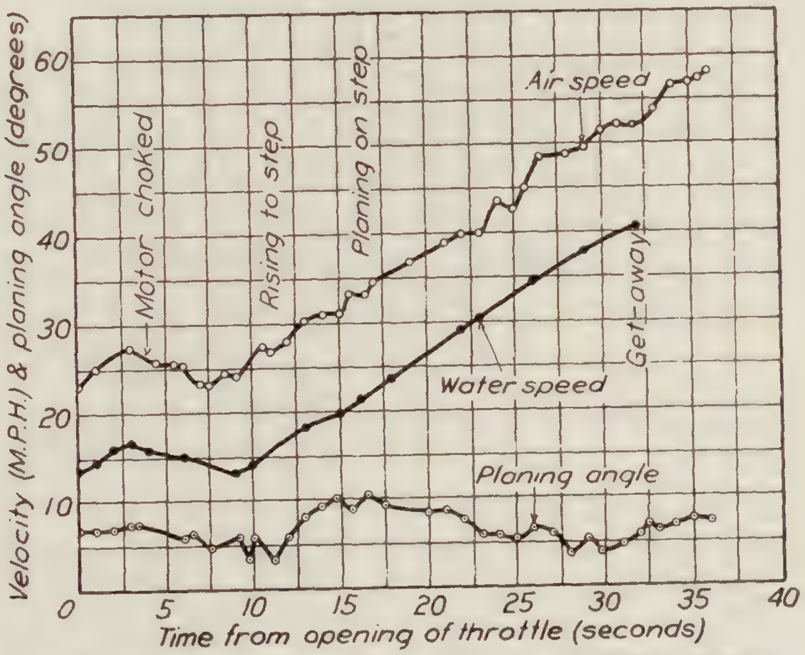


FIG. 12.—Method: Normal. Weight, 6,000 pounds. Rippled water

Figures 9 to 15 show take-offs made in the pilot's usual manner. The planing oscillations are not as pronounced in these runs, and it is quite probable that they were somewhat broken up by control opposing oscillation. Figure 12 shows a run in which the engine choked up at 3 seconds and picked up again at 9 seconds. The oscillations at 10 seconds were probably started by the sudden application of thrust. In the down wind run (fig. 13) considerable air speed was needed to maintain directional control while turning, so that by the time the seaplane was actually headed down wind it was already on the step. At 28 seconds a region of higher wind velocity was encountered which was detrimental to the lift and allowed the seaplane to settle, thus increasing the resistance enough to lower the water speed.

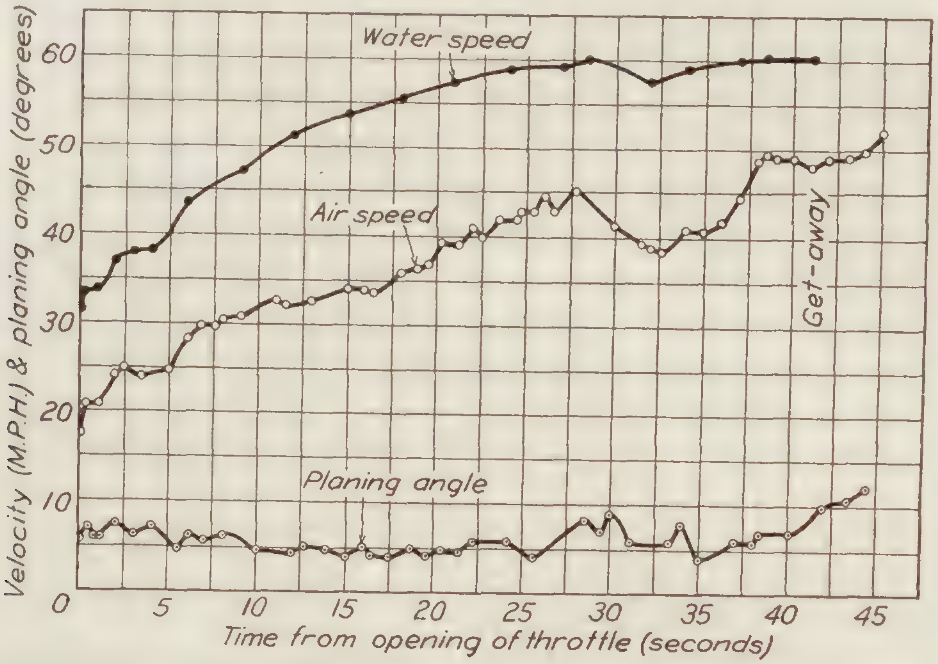


FIG. 13.—Down wind. Method: Normal. Weight, 6,000 pounds. Rippled water

Figures 14 and 15 show runs made with a gross load of 6,800 and 7,500 pounds, respectively. Compared to the curves of the light load runs, these are more characteristic of the take-off of a normally loaded seaplane. The velocity increase or acceleration is large while plowing, small while changing from plowing to planing, and again large while planing, indicating, respectively small, large, and small resistance. The transition stage starts at about 19 M. P. H., but the velocity of its ending varies somewhat with load as does also the maximum angle, which is 8° to 10° higher than the normal planing angle. With the 6,800-pound load the planing condition is reached at 21 M. P. H., but with 7,500 pounds the planing does not appear to start until 25 M. P. H. As seen here, the increase in loading does not materially affect the speed at the beginning of the transition stage, but does appear to delay the start of the planing stage. Control

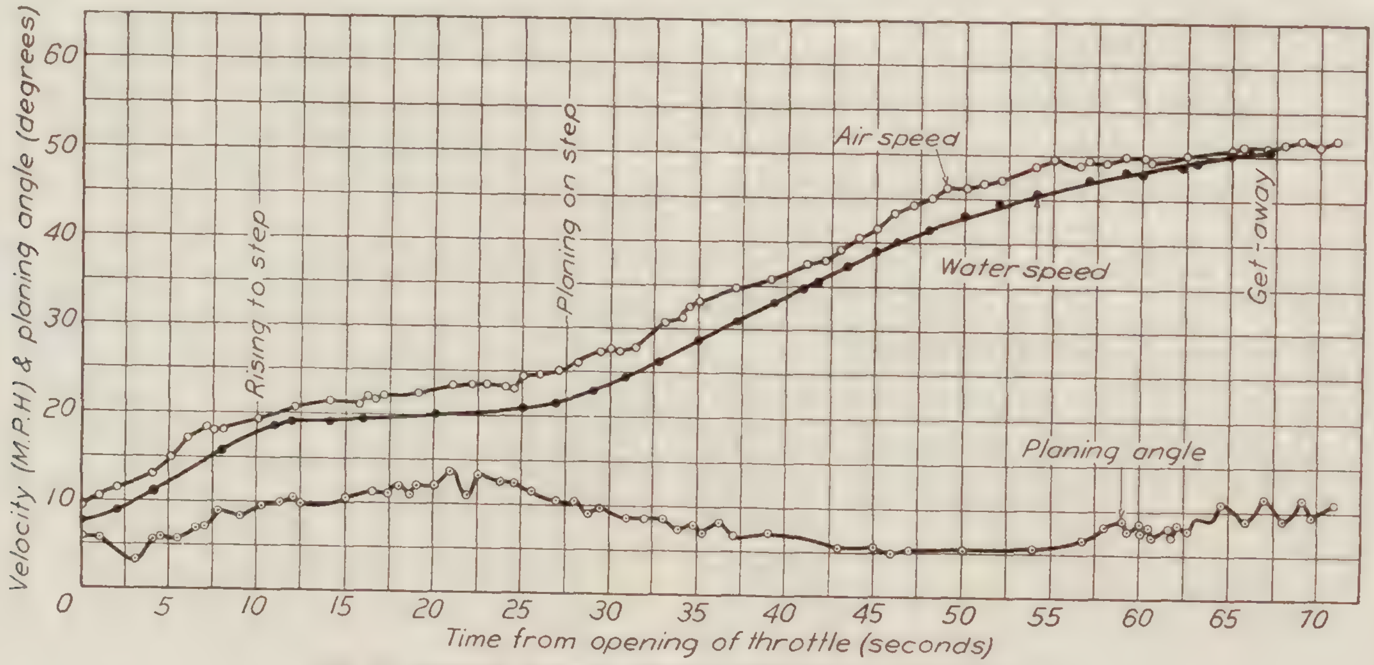


FIG. 14.—Method: Normal. Weight, 6,800 pounds. Smooth water

effectiveness is desired when planing commences, as it is then that objectionable oscillations are apt to occur, but this small variation in velocity at the start of planing would affect the control available only slightly. In comparing the runs of different loads it is seen that while two or three seconds are required to get through the transition stage with a light load, 12½ seconds are required for the 6,800-pound load, and 23 seconds for the 7,500-pound load. As in the light-load runs, the slope of the water-speed curve decreases at high planing speeds, thus showing the same tendency toward increase in resistance. At 35 M.P.H. the normal planing angle of 5° is attained.

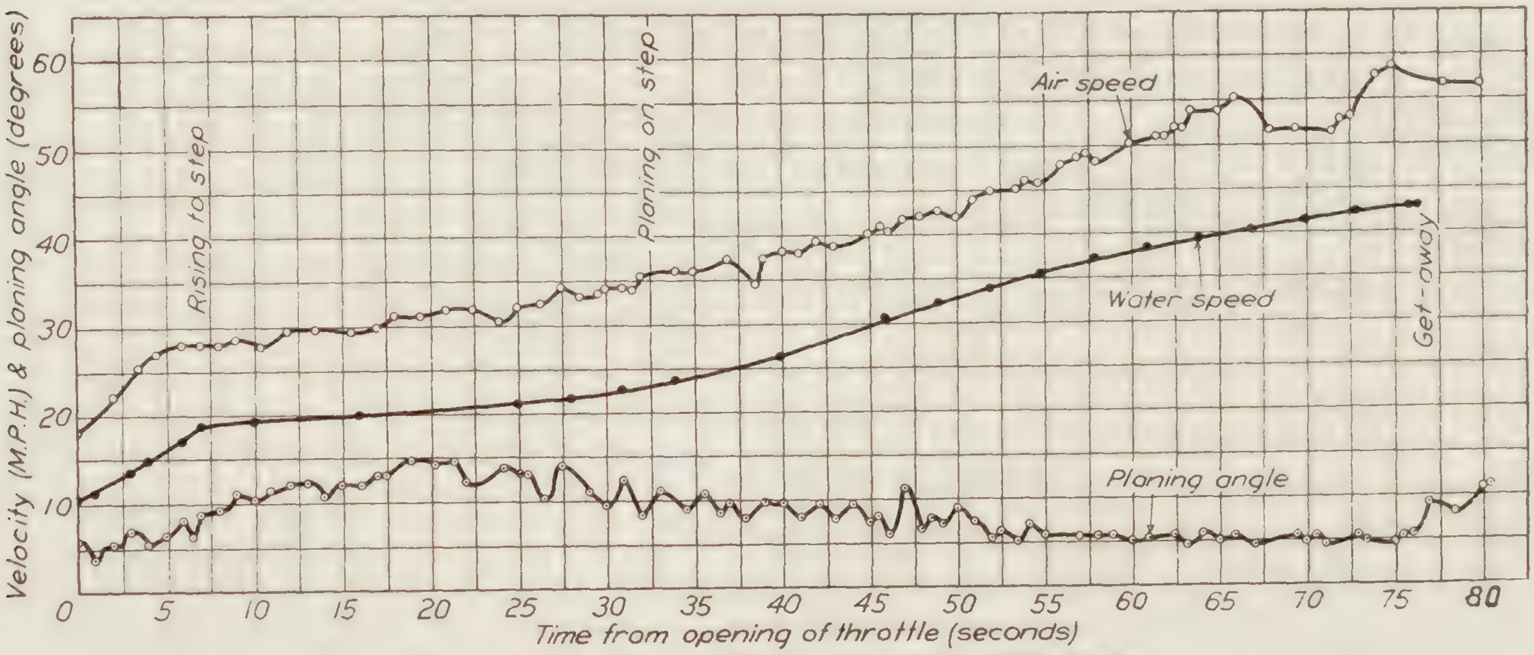


FIG. 15.—Method: Normal. Weight, 7,500 pounds. Rippled water

While planing at lower velocities with the 7,500-pound load there is considerable oscillation, which it is believed was not entirely due to the method of control. As this was found to be true also of the light-load runs, it appears reasonable to assume that the DT–2 is slightly unstable while planing below velocities of 40 M.P.H., whether lightly or heavily loaded. Some trouble was experienced in bringing the nose up to a get-away angle with the 6,800-pound load. Since this difficulty was not experienced with the 7,500-pound load, the smooth water surface, which it is known often hinders planing, must have been mainly responsible for it.

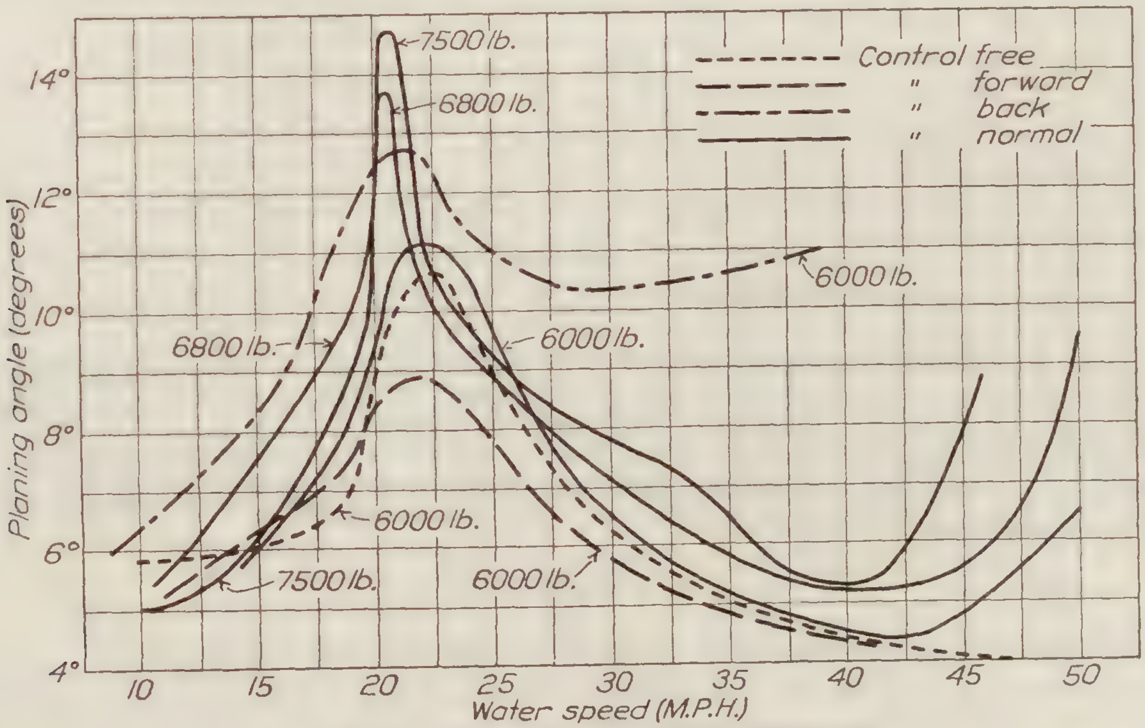


FIG. 16.—Variation in planing angle with water speed

The relation of the attitude of the seaplane to water speed when subject to various longitudinal controls and different loadings is plotted in Figure 16. The effect of the longitudinal control on a lightly loaded DT–2 during a take-off is such that the transition angle can be varied from 9° to 13° as desired. With a full load the trimming moments of the floats overcome those of the control to such an extent that the trimming range at this time would probably be decreased to less than 2 degrees. (Reference 1.) In the take-offs with increased load the maximum transition angle becomes larger, and it is recorded as occurring at a water speed which is 1 M. P. H. greater than that which occurred at the same angle with light load. However, the error in the measurement of velocity and synchronization may be this amount so it is reasonable to assume that they occur at practically the same velocity. The speed, at which maximum angle and maximum resistance are attained, with change of loading is characteristic of the float. The shape and angles of the forebody are probably the dominating factors. (Reference 6.) The enlargement of the angular control range with increasing velocity is shown by the divergence of the curves of control forward and control back. The proximity of the curve of control forward to that of the control free at high speeds shows that the positive restoring moment of the floats is such that very little trimming by the head can be secured.

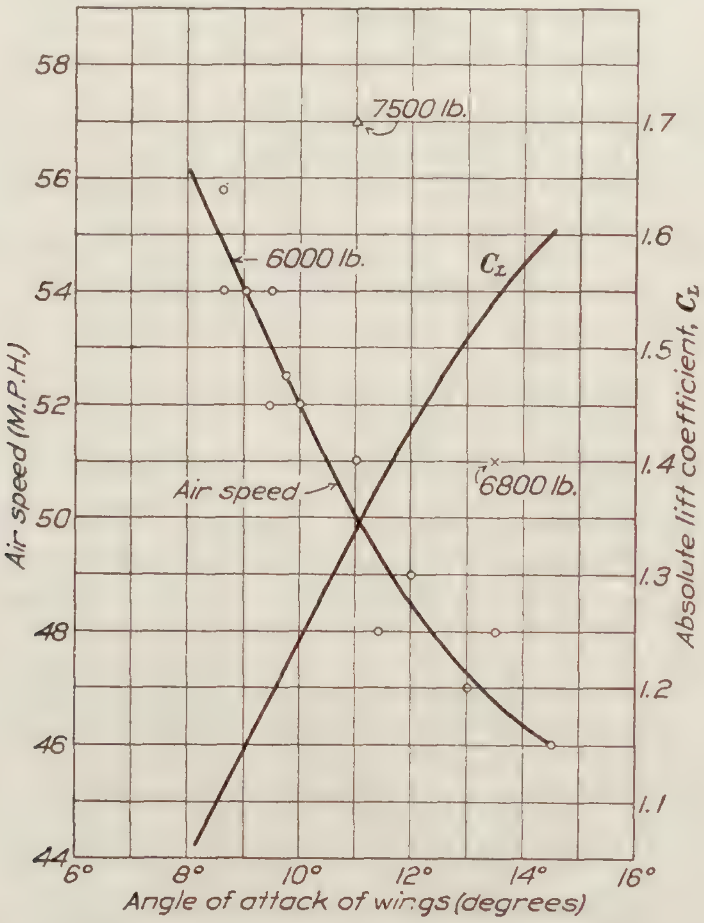


FIG. 17.—Velocity and lift coefficient at various get-away angles

In Figure 17 are plotted the angles of attack of the wing at various get-away speeds. The lift coefficient curve, C_L, as obtained from the angle-velocity curve, is also given. The error caused by ground effect has not been considered. The DT–2 will get away light through an angular range of 8° to 14° at corresponding velocities of 56 to 46 M. P. H., or through about 22 per cent of the speed range.

CONCLUSIONS

The DT–2 will oscillate steadily at low planing speeds with free control. The oscillations are amplified when planing on smooth water and when the elevators are held down but these can be damped by control opposing the oscillations. At high planing speeds the DT–2 is more stable, caused no doubt by the damping effect of the V-bottom.

The total resistance increases with increase of planing velocities above 37 M. P. H. The sharpness of the included angle of the V-bottom, which has a 15° slope, is believed to be responsible for this.

With the light float loading (63.3 lb./inch of beam), the stability of the DT–2 is as good as with heavier loadings and it has no tendency to porpoise at high speeds. Light loadings are often objectionable because planing and porpoising occur early, i.e., at an air speed which is too low to provide effective control. On the DT–2, however, light loading is not objectionable, for while the need for control when planing starts comes at a slightly lower velocity, the effectiveness of the control is better because the trimming moments of the floats are less.

The seaplane will trim by the stern until an angle is reached that gives the required dynamic lift. The relation between the loading and this maximum planing angle is approximately linear.

REFERENCES AND BIBLIOGRAPHY

Reference 1. Crowley, J. W., jr., and Ronan, K. M.: "Characteristics of a Single-Float Seaplane During Take-off." N. A. C. A. Technical Report No. 209, 1924.

Reference 2. Crowley, J. W., jr., and Ronan, K. M.: "Characteristics of a Boat-type Seaplane During Take-off." N. A. C. A. Technical Report No. 226, 1925.

Reference 3. Norton, F. H.: "N. A. C. A. Recording Air-speed Meter." N. A. C. A. Technical Note, No. 64, October, 1921.

Reference 4. Reid, H. J. E.: "The N. A. C. A. Recording Tachometer and Angle of Attack Recorder." N. A. C. A. Technical Note No. 156, August, 1923.

Reference 5. Baker, G. S.: "Some Notes on Floats for Seaplanes of the Single-Float Type (14th series)." British Advisory Committee for Aeronautics, R. & M. No. 437, 1918.

Reference 6. Baker, G. S., and Keary, E. M.: "Experiments with Model Flying Hulls and Seaplane Floats (19th series). Possibility of Loading a Flying Boat, the Beam and Angle of Forebody Being Varied." British Advisory Committee for Aeronautics, R. & M. No. 655, 1920.

Reference 7. Baker, G. S., and Millar, G. H.: "Experiments with Models of Hydro-Aeroplane Floats (2d and 3d series)." British Advisory Committee for Aeronautics, R. & M. 98, 1913.

Guidoni, A.: "The Gliding Surface of Seaplane Floats." Aviation, June 1, 1920.

Richardson, H. C.: "Hydromechanic Experiments with Flying Boat Hulls." Smithsonian Miscellaneous Collections, volume 62, No. 2.

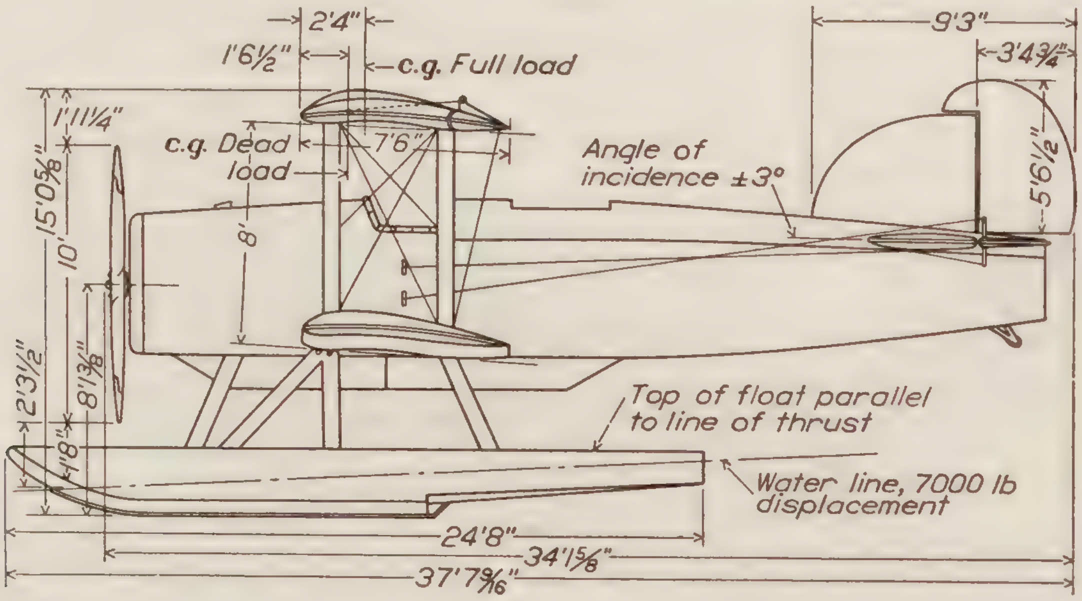
Hunsaker, J. C.: "Naval Architecture in Aeronautics." The Aeronautical Journal, July, 1920.

"DT Twin Floats." U. S. Experimental Model Basin, Navy Yard, Washington, D. C. Report of Additional Experiments with Model No. 2394, November, 1924, No. 103.

APPENDIX NO. 1

CHARACTERISTICS OF THE DT-2 SEAPLANE

Type	Twin float tractor biplane.
Wing area	707 square feet.
Angle of incidence of wings	3°.
Angle of incidence of pontoon	0°.
Weight, as tested	6,000 to 7,500 pounds.
Engine	Liberty, 370 HP. at 1,500 R. P. M.
Wing loading	8.5 to 10.6 pounds per square foot.
Power loading	16.2 to 20 pounds per HP.
Span	50 feet.
Float tread	10 feet.
Wing section	U. S. A. 27.



APPENDIX NO. 2

COMPARISON OF THE TAKE-OFF CHARACTERISTICS OF THE THREE TYPES OF SEAPLANES

The general take-off characteristics of the three types of seaplanes are repeated here. Because of the variable conditions only the most obvious qualities attributable to the different types are emphasized. For instance the stability characteristics of a float are as dependent on the air, thrust, and weight forces as upon the water forces. It is not permissible then to say that the stability of one type as indicated by one example is superior to that of another unless this representative shows qualities which are known from other sources to be characteristic. It is desired, of course, to get off the water quickly and easily. To do this the seaplane's resistance must be small or its power large, while it must plane stably and trim easily.

Table I is a recapitulation of the results obtained in the tests of the three types of seaplanes. The data tabulated therein are taken directly from the results of the individual tests or from U. S. Navy charts of characteristics, with the exception of the float loadings. The first float loading given, $\frac{\text{total weight}}{\text{beam}}$, is only a relative term, as at any but zero velocity the wings carry some of the weight. The float loading at peak angle was obtained by subtracting the weight supported by the wings at peak angle from the total weight and using this value in the expression $\frac{\text{weight}}{\text{beam}}$. The load supported by the wings was computed from the get-away C_L curves given in each report.

A study of the original take-off curves of all three shows that water with a smooth surface offers more resistance, especially at the transition stage, than does a rougher surface.

As mentioned before, it is not permissible to consider the stability characteristics of one seaplane as being typical. However, these tests bear out the generally accepted axiom that the flatter the bottom the greater the tendency toward planing instability. On smooth water, at low planing speeds, the N–9H with a 7½° float was slightly unstable, the DT–2 with a 15° float had steady oscillations, while the F–5L with a 20° V bottom had damped oscillations. The stability of the DT–2 is considerably improved at the higher planing speeds while that of the others does not change. The planing stability of all three is improved on water with a roughened surface. This means that model float testing without the employment of a wave-making apparatus is simulating the worst conditions, as regards stability and resistance.

An idea of the controllability of the three seaplanes is gained by recording the approximate range through which the seaplane can be trimmed. The F–5L has a 6° range at high planing speeds, which is an indication that the float can be trimmed through a sufficient range to get away as desired. However, this trimming can not be done quickly nor easily, so that it is especially difficult to get the F–5L off on smooth water. The section abaft the steps is probably a liability in this case because if it is not sharply inclined upward it hinders trimming. The inefficient tail surfaces are also a factor in the poor controllability of the F–5L.

The control methods used to take-off vary greatly with different pilots and are the subject of many discussions. By "rocking," as used in the table, is meant the periodic up-and-down movement of the elevators. By "flipping" is meant pulling the elevators up quickly and attempting to hold the position attained, then easing the elevators down and repeating the process. It is rather general practice to "rock" a seaplane slightly to get it on the step. As is seen in the table, little or no control is necessary to take off, except to trim to a get-away angle. In general it can be said that the best or worst control aids or hinders but little until the get-away, when proper control is usually necessary to bring the seaplane to a flying angle.

TABLE I

Seaplane Type Class	N-9H Single float Training	DT-2 Twin float Torpedo	DT-2 Twin float Torpedo	F-5L Boat Patrol
CHARACTERISTICS				
Weight (pounds)	2,970	7,500	6,000	13,700
Wing area (square feet)	496	707	707	1,397
Wing loading (pounds per square foot)	6.0	10.6	8.5	9.8
Horsepower	150	370	370	720
Power loading (pounds per horsepower)	19.8	20.0	16.2	19.0
Float beam (inches)	41.5	47.5	47.5	120
Float loading (pounds per inch of beam)	71.5	79.0	63.3	114
Vee at step, slope (degrees)	7½	15	15	20
TAKE-OFF PERFORMANCE				
Take-off time, average (seconds)	20	75	25	45
Time in transition stage (seconds)	5	23	3	5
Angle of attack at get-away (degrees)	8-16		8-14.5	11-19
Get-away speeds (M. P. H.)	41-53		45-56	51-58
Ratio—$\frac{\text{Get-away speed range}}{\text{Flight speed range}}$	0.40		0.22	0.25
Normal planing angle [4] (degrees)	4	5	5	6
Peak angle (degrees)	12	15	12	13
Wing lift (approximate) at peak angle (pounds)	1,100	2,340	1,930	3,425
Float loading (approximate) at peak angle, pounds per inch of beam (degrees)	45	54.5	42.8	85.5
Trimming angles:				
Plowing	3.5-4.5		5-6	
Transition	10.5-12		9-13	12-13
Planing (low speed)	5.5-8.5		5.5-10.5	5-9
Planing (high speed)	4-12		4-11	4-12

[4] Angle assumed when planing free at high speeds.

Seaplane Type Class	N-9H Single float Training	DT-2 Twin float Torpedo Weight 7,500 lb.	DT-2 Twin float Torpedo Weight 6,000 lb.	F-5L Boat Patrol
STABILITY				
Smooth water:				
Plowing and transition	Stable	Stable	Stable	Stable.
Planing (low speed)	Slightly unstable	Steady oscillations	Steady oscillations	Damped oscillations.
Planing (high speed)	do	Damped oscillations	Damped oscillations	Do.
Rippled water:				
Plowing and transition	Small oscillations	Stable	Stable	Stable.
Planing (low speed)	Damped oscillations	Damped oscillations	Damped oscillations	Do.
Planing (high speed)	Stable	Stable	Stable	Do.
CONTROLLABILITY				
Trimming ability at get-away:				
Smooth water	Good	Poor	Good	Very poor.
Rippled water	do	Good	do	Fair.
CONTROL NECESSARY				
Smooth water:				
To start to rise	None	None	None	None.
To start planing	Forward or slight flipping.	Quick forward	do	Do.
While planing	None	None	do	Do.
To get-away	Slightly aft	Aft or slight flipping	Slightly aft	Steady flipping to strenuous rocking.
Rippled water:				
To start to rise	None	None	None	None.
To start planing	do	Quick forward	do	Do.
While planing	do	None	do	Do.
To get-away	Slightly aft	Aft	Slightly aft	Aft to steady flipping.

REPORT No. 243

A PRELIMINARY STUDY OF FUEL INJECTION AND COMPRESSION IGNITION AS APPLIED TO AN AIRCRAFT ENGINE CYLINDER

By ARTHUR W. GARDINER
National Advisory Committee for Aeronautics

REPORT No. 243

A PRELIMINARY STUDY OF FUEL INJECTION AND COMPRESSION IGNITION AS APPLIED TO AN AIRCRAFT ENGINE CYLINDER

By Arthur W. Gardiner

SUMMARY

This report summarizes some results obtained with a single cylinder test engine at the Langley Field Laboratory of the National Advisory Committee for Aeronautics during a preliminary investigation of the problem of applying fuel injection and compression ignition to aircraft engines. For this work a standard Liberty engine cylinder was fitted with a high compression, 11.4 : 1 compression ratio, piston, and equipped with an airless injection system, including a primary fuel pump, an injection pump, and an automatic injection valve.

The results obtained during this investigation have indicated the possibility of applying airless injection and compression ignition to a cylinder of this size, 5-inch bore by 7-inch stroke, when operating at engine speeds as high as 1,850 R. P. M., although the unsuitability of the Liberty cylinder form of combustion chamber for compression ignition research probably accentuated the difficulties to be overcome. No difficulty was experienced in metering and injecting the small quantities of fuel required. A minimum specific fuel consumption with Diesel engine fuel oil of 0.30 pound per I. HP. hour was obtained when developing about 16 B. HP. at 1,730 R. P. M. Specific fuel consumption increased for higher loads at these speeds. A maximum power output of 29.7 B. HP. at 1,700 R. P. M. was obtained but could not be maintained for more than one-half minute due to piston failure. Mean effective pressures approaching standard aircraft engine practice could not be obtained, due in part, it was attributed, to the unsuitable form of the Liberty cylinder combustion chamber. Excessive maximum combustion pressures were encountered when developing only about 60 pounds B. M. E. P. at 1,700 R. P. M., and piston life was very short. The engine could be idled with regular firing at 400 R. P. M., but acceleration under load was not satisfactory, due probably to the fixed timing of injection during any particlar run.

INTRODUCTION

The application of airless fuel injection and compression ignition to aircraft engines is attractive because it enables the use of less inflammable and cheaper fuel, and gives, theoretically, better fuel economy at part loads than is obtained with the carburetted engine. While compression ignition eliminates the electric ignition system with its attendant troubles, it can not be said, as yet, that the fuel injection apparatus would be any less troublesome.

Since there appeared to be no published data available on the results of tests of an aircraft engine operating with fuel injection and compression ignition, this preliminary investigation was undertaken in order to learn something of the problem of airless, or solid, fuel injection as applied to aircraft engines.

The tests herein reported were conducted under the direction of Robertson Matthews.

DESCRIPTION OF APPARATUS AND METHODS

A standard Liberty cylinder, 5-inch bore and 7-inch stroke, without alterations, and having standard Liberty valve timing, was mounted on a single cylinder base and coupled to a 45/75 Sprague electric cradle dynamometer for the present tests. A photograph of the engine, showing the location of the injection valve and injection pump, is given in Figure 1.

To adapt the engine for use with compression ignition, it was necessary to remove the electric ignition system, to provide a drive shaft for the injection pump, mounted in the previous location of the ignition distributor head, and to substitute a high compression piston for the standard piston.

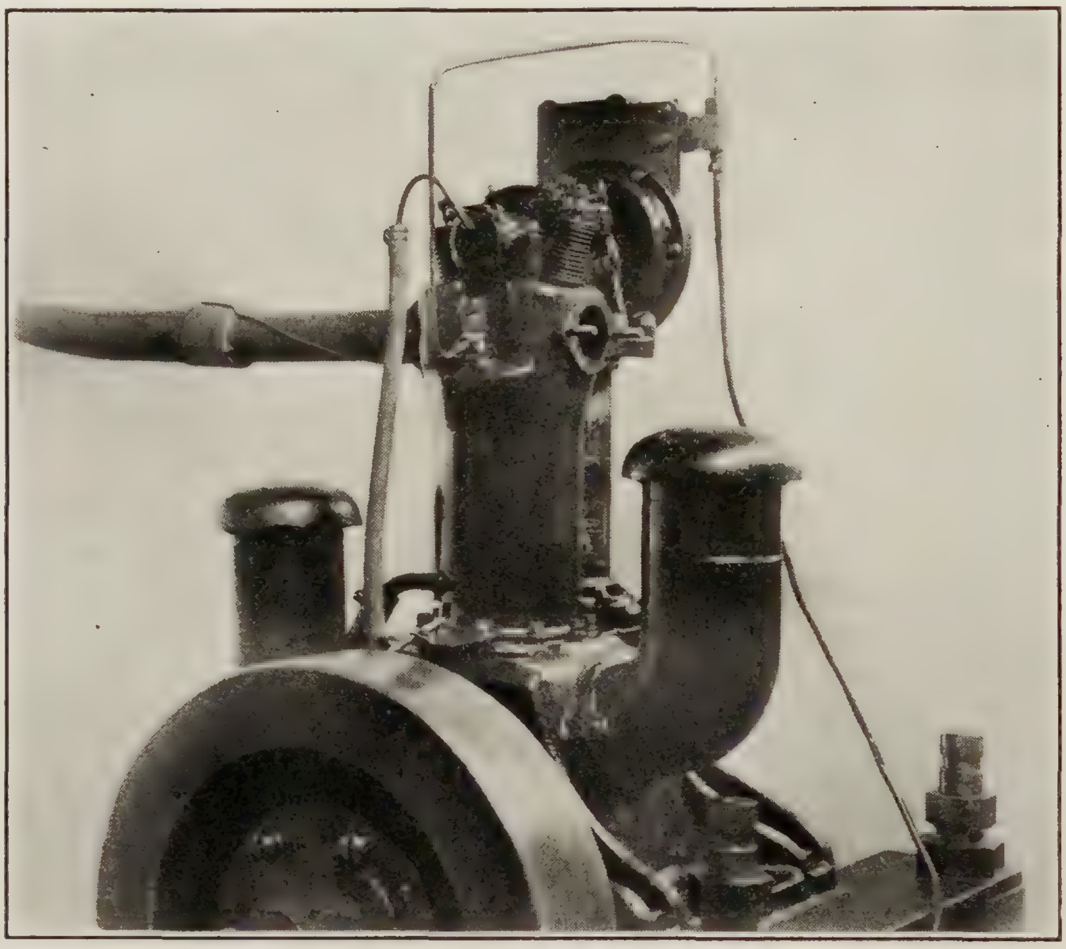


FIG. 1.—Single-cylinder Liberty engine equipped with airless injection system

Additional equipment for the engine included the primary fuel system, the injection pump, and the automatic injection valve.

PISTON DESIGN

In selecting the compression ratio for the Liberty cylinder operating on compression ignition, it was desired to use a ratio that would insure compression ignition when starting with a cold engine. At the same time, it was desired to use the lowest practical ratio in order to minimize the cranking effort required in starting, to keep the piston weight a minimum, to provide the largest space over the piston for the injection of fuel, and to keep combustion pressures as low as possible.

A fairly high compression ratio, 11.4:1, was finally chosen, being based only on a consideration of those conditions within the cylinder itself which might have an appreciable influence on the final compression pressure and temperature. Other factors which might logically have influenced the selection of the compression ratio, such as providing a compression ratio that would insure reliable engine operation under altitude conditions, or using a higher compression ratio than required from the standpoint of compression ignition only in order to provide a given temperature and pressure at the time the fuel would be injected, were not considered, as it was thought unnecessary at this stage of the investigation.

In order to secure the necessary compression pressure, it was required, with the Liberty form of combustion chamber, that the piston extend almost to the top of the cylinder. A conventional form of piston head, such as a dished head, could not be used without sacrificing compression pressure. Further, as the injection valve would be located in one of the spark-plug holes, which in the Liberty cylinder are off center, it appeared that the best distribution of fuel would be obtained by directing the fuel spray across the top of the piston. These conditions necessitated the adoption of an irregular form of head, having fluting or shallow grooving which would conform more or less to the spray shape, thus reducing deposition of fuel on the piston head. As the standard Liberty connecting rod was used, it was necessary to make the piston longer above the wrist pin bosses, as shown in Figure 2. Sectional drawings of the high compression pistons are shown in Figures 3 to 7, inclusive. Figures 3 and 4 show the form of piston head with the deep fluting which was first used. Figures 5, 6, and 7 show the form of head later adopted in an attempt to lower the rim of the piston and obtain better distribution of fuel to the air around the piston.

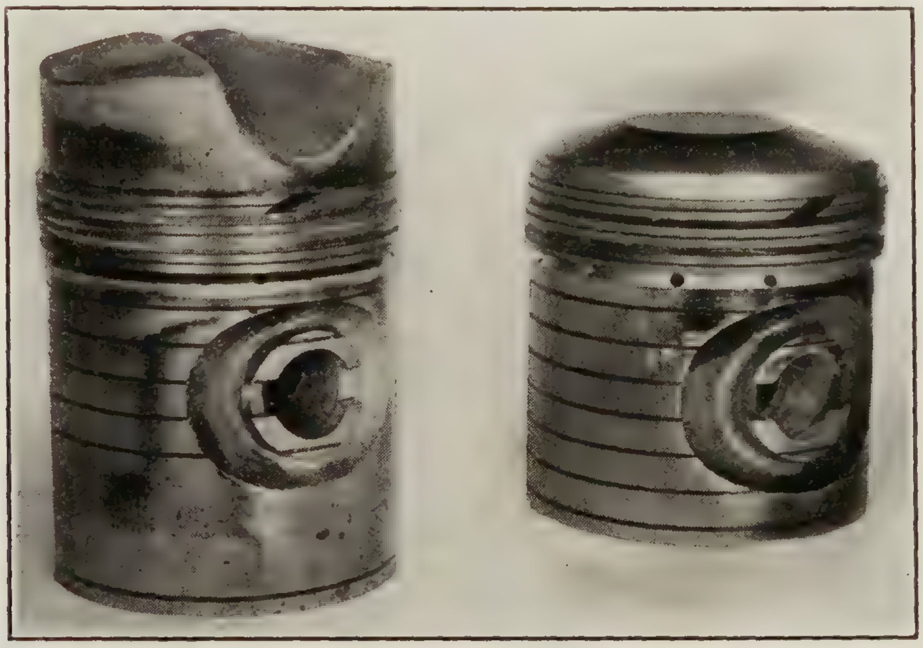


FIG. 2.—Comparison of high-compression piston (11.4:1) with the standard Liberty Army-type piston (5.4:1.)

Aluminum alloy, magnesium alloy, and cast-iron pistons were tried in an attempt to obtain a piston material that would withstand the severe conditions of temperature and pressure obtaining during these tests. The standard Liberty piston, 5.4 ratio, with three standard rings weighs 3.75 pounds, whereas the high-compression pistons with rings had the following weights: Aluminum alloy piston 2, 5.13 pounds; aluminum alloy pistons 3 and 4, 4.92 pounds; cast-iron pistons 7 and 8, 8.89 pounds; magnesium alloy piston 12, 3.82 pounds; and magnesium alloy piston 14, 4.62 pounds.

PRIMARY FUEL SYSTEM

A gear pump and a three-throw plunger pump, both of commercial types, were used. A small volumetric fuel tank, having a capacity sufficient for a two to three-minute run at maximum load and speed, was used in making fuel consumption tests. This tank could be refilled from the by-passed overflow of the primary pump without stopping the engine. The only strainer in the fuel system was placed between the primary and injection pumps, and consisted of a double layer of 150-mesh copper screen.

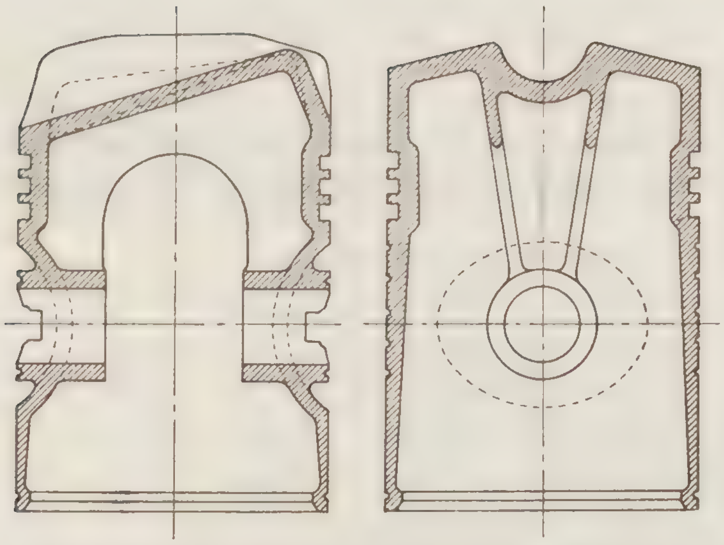


FIG. 3.—Sectional views of pistons 1 and 2 (aluminum alloy)

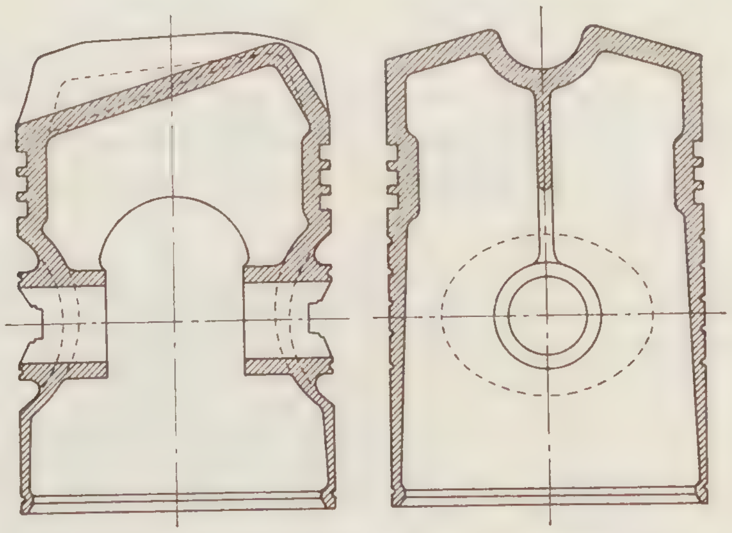


FIG. 4.—Sectional views of pistons 3 and 4 (aluminum alloy)

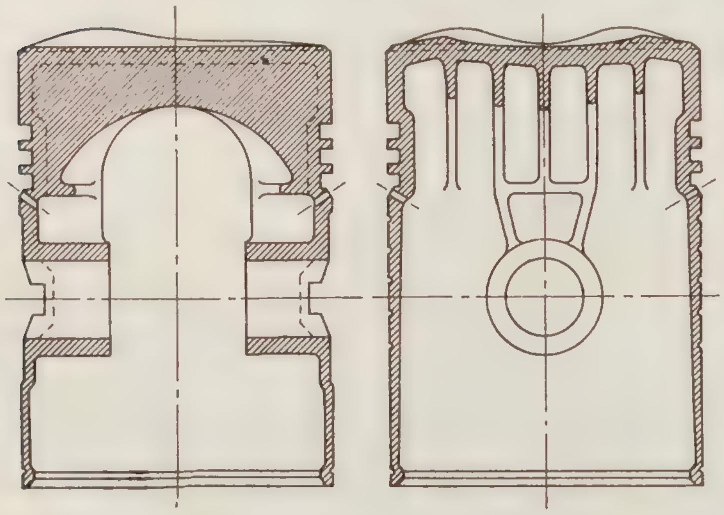


FIG. 5.—Sectional views of pistons 5 and 8 (aluminum alloy and cast iron)

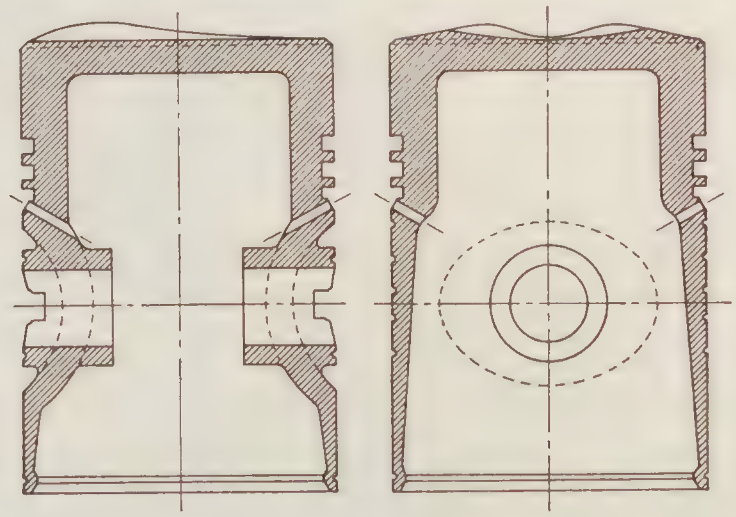


FIG. 6.—Sectional views of piston 12 magnesium alloy)

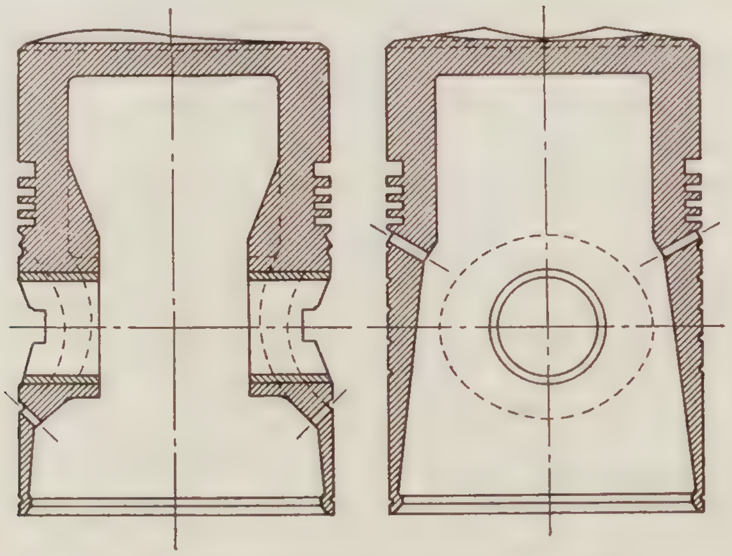


FIG.—7. Sectional views of piston 14 (magnesium alloy)

INJECTION PUMP

A photograph of the injection pump, and a sectional drawing of the pump as originally constructed are given in Figures 8 and 9, respectively. This pump was used to meter and inject the fuel, the amount of fuel injected being controlled by adjusting the length of the pump plunger stroke. The floating plunger, $\frac{7}{32}$ inch in diameter, was a lapped fit and was used without packing. It was driven forward during the injection stroke by the spring, previously compressed by means of the radial cam, and was returned solely under the action of the primary fuel pressure. The plunger stroke began when the rocker arm follower dropped off the radial cam, and ended when the spring cap came against the adjustable stop. A 173-pound helical spring was used, which exerted a force of 285 pounds on the pump plunger at the beginning of the plunger stroke. Two spring-loaded ball check valves in series were used both for the intake side and for the discharge side of the pump. Seamless steel tubing, $\frac{1}{8}$ inch inside, was used for the high-pressure fuel line between the injection pump and injection valve.

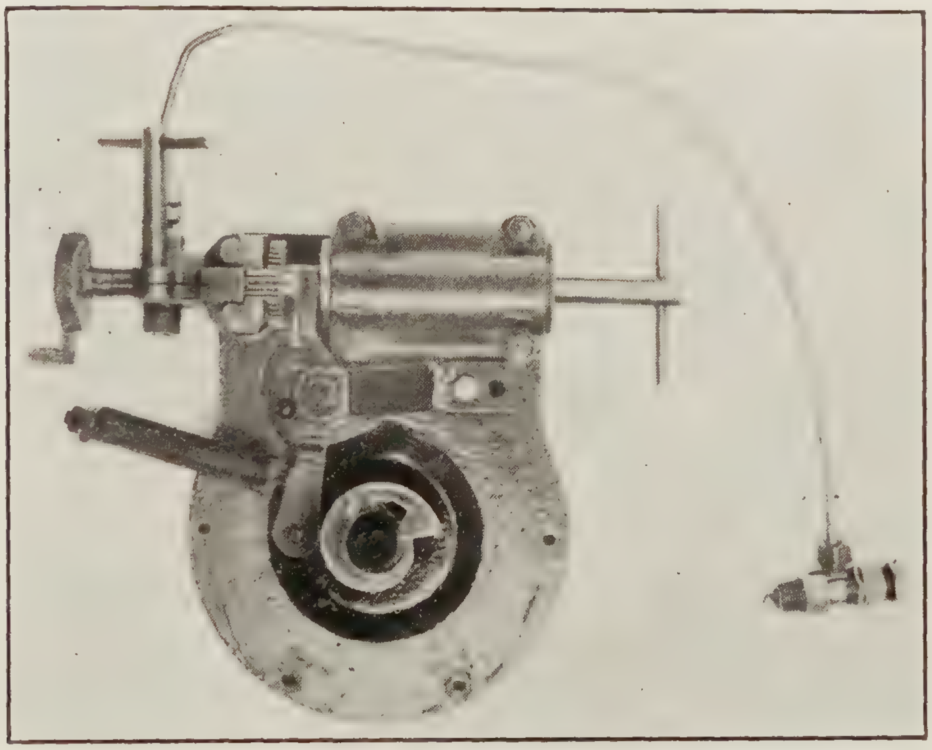


FIG. 8.—Injection pump and injection valve

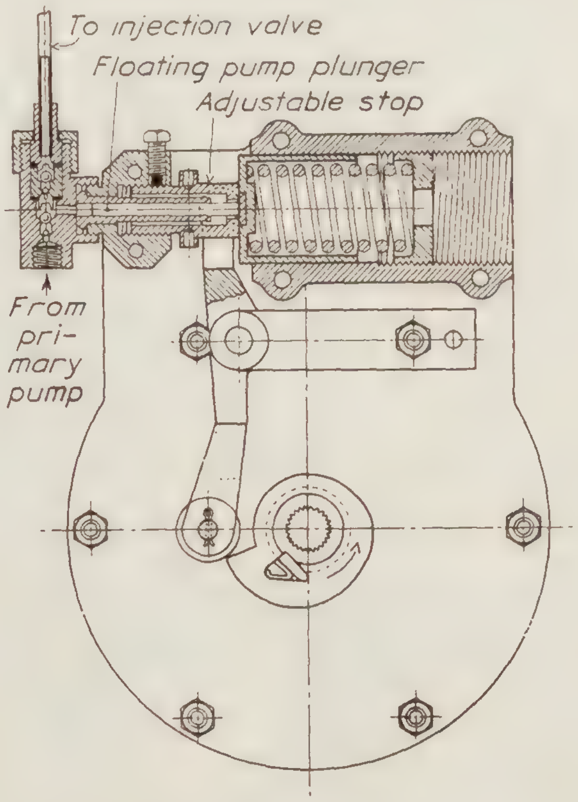


FIG. 9.—Spring-actuated injection pump

INJECTION VALVE

Certain limitations were placed upon the design of the injection valve: Outside dimensions were limited as it was planned to locate the valve in the metric spark plug hole, which had a diameter at the root of the thread of only 0.64 inch; it was necessary that the moving parts of the valve be light in order to meet high-speed requirements (15 injections per second at 1,800 R. P. M. of the engine); it was desirable to have a minimum volume of fuel in the valve in order to reduce the amount of fuel to be compressed before injection occurred, and to reduce the tendency for "dribbling"; and the direction of the fuel jet had to be at an angle with the axis of the valve in order to spray across the piston.

A drawing showing a section through the injection valve is shown on Figure 10. The valve stem, which was a lapped fit in the valve body, lifted and seated automatically with change of pressure in the high-pressure fuel line, and was free to lift until the spring coils closed. The opening pressure was fixed by the spring load on the valve stem. Small changes in opening pressure could be obtained by adjusting the spring cap, but large changes in opening pressure were effected by using a series of graded springs, which gave a range of opening pressures from 1,200 pounds per square inch to 5,400 pounds per square inch. These opening pressures were determined on a gauge tester; the maximum pressures in the high-pressure fuel line probably would be much higher.

Two types of nozzles (fig. 10) were used with the above injection valve: The plain orifice and the impact or lipped type. The plain orifice type, having but a single orifice, 0.021 inch in diameter, was first tried. A similar tip, having a single 0.016-inch diameter orifice was next tried, as was also the two-hole type, having two 0.012-inch diameter orifices. The plain nozzles, however, had nothing to recommend them except simplicity, and conformity between shape of jet and piston fluting. The fuel injected from this type nozzle was not finely atomized. Moreover, the plain jet gave too much penetration for the size cylinder used, as there was evidence that fuel was being deposited on the relatively cold combustion chamber wall opposite the injection valve. Consideration of these conditions led to the adoption of the lipped nozzle which gave less penetration and better atomization and distribution. As the Diesel engine fuel oil burned cleanly, the lipped nozzle could be used without excessive amounts of carbon being deposited thereon. No erosion of the lip was noticeable after running for several hours with Diesel engine fuel oil. With a lip of the approximate proportions shown in the figure, the following orifice diameters were tried: 0.012, 0.014, 0.018, 0.023, and 0.026 inch.

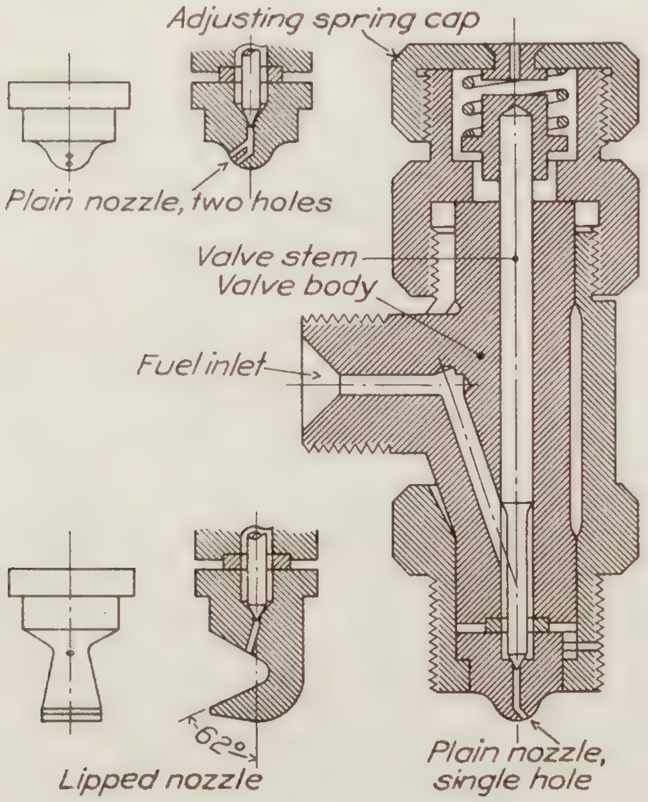


FIG. 10.—Automatic injection valve

FUEL

A high-grade Diesel engine fuel oil, having a Saybolt viscosity of 43 seconds and a specific gravity of 0.87 (34° B.) at 60° F., was used for most of the tests. Kerosene was tried in order to obtain a comparison with Diesel engine fuel oil.

PRECISION AND METHODS

Care was exercised to obtain brake horsepower, friction horsepower, and fuel consumption with a minimum of error possible with the apparatus used. In presenting the data, however, no corrections for barometer or air temperature have been applied.

Torque was measured with a Kron scale having minimum graduations of 0.2 pound. Revolutions were measured with a revolution counter and stop watch synchronized by means of a solenoid switch. With a dynamometer torque arm of 15.75 inches the equation for power is

$$\text{HP.}=\frac{\text{Scale reading (lb.)} \times \text{R. P. M.}}{4{,}000}$$

Indicated power was obtained by the addition of brake power and friction power, the latter obtained by motoring the engine with the dynamometer. Recent tests (Reference 1) made elsewhere have shown that this method of securing indicated power may be in error by as much as 10 per cent.

Fuel consumption was obtained by observing the time required to empty a small volumetric fuel tank.

Maximum combustion pressures were measured by means of a Mader microindicator, and a spring-loaded relief valve. Values for maximum pressures obtained by these methods were considered inaccurate but indicative.

An Okill indicator was used to measure compression pressures.

The method of starting, without resorting to spark ignition, with compression pressures above 300 pounds, and jacket water temperature about 100° F., consisted in motoring the engine by means of the dynamometer at speeds as low as 500 R. P. M. and then starting the injection of fuel. By this method, the engine started firing within a few revolutions after fuel was admitted. The difficulty experienced in starting the engine with some of the pistons, which gave compression pressures as low as 270 pounds, was overcome by attaching a long pipe to the engine intake, thus obtaining an increase in final compression pressures. (Reference 2.)

Variation in the timing of injection was obtained by removing and resetting the injection pump cam on its splined shaft. This shaft had 100 splines, so that a minimum adjustment of 7.2 degrees, measured in terms of crank angle, could be obtained. Optimum injection timing was obtained by making trial runs.

The lag of the fuel jet behind the pump cam timing and the interval of injection were obtained by injecting the fuel, while motoring the engine, against paper targets shellacked to the flywheel.

DISCUSSION OF RESULTS

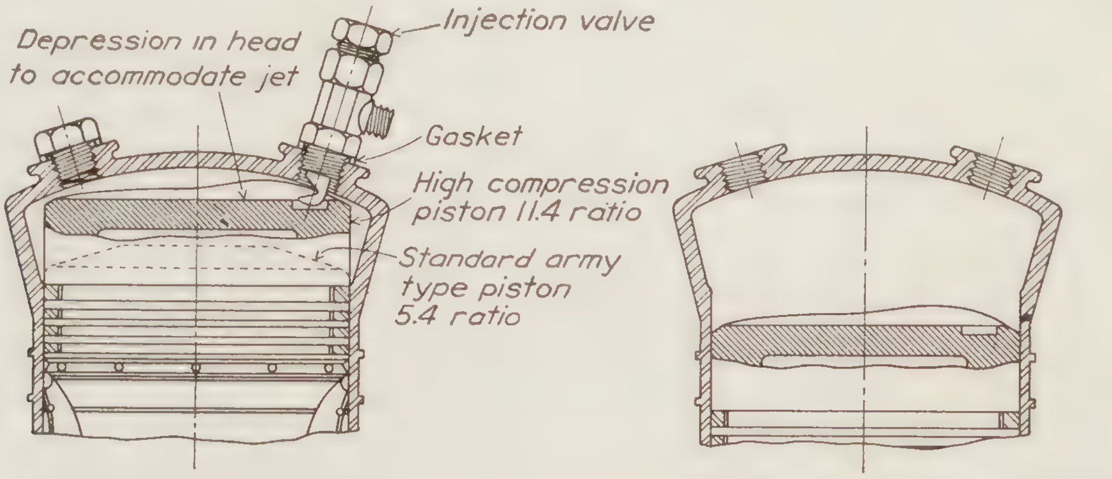
Some preliminary tests were made using the plain nozzle type injection valve previous to adopting the lipped nozzle. During these tests using pistons of the deep-fluted type, a maximum of 22 B. HP. at 1,800 R. P. M., or 109 pounds I. M. E. P., was obtained with the plain nozzle having a single 0.018-inch orifice; but the fuel consumption was excessive, about 0.84 pound per B. HP. hour, and there was considerable exhaust smoke. The best combination of power and fuel consumption, 20 B. HP. at 1,800 R. P. M., and 0.62 pound per B. HP. hour, was also obtained with the 0.018-inch orifice. Tests with both the single 0.016-inch orifice and the nozzle having two 0.012-inch orifices gave 18 B. HP. at 1,800 R. P. M. with a fuel consumption of 0.64 pound per B. HP. hour. In order to obtain the above power it was found necessary to advance the timing of the injection pump cam to 61 degrees before T. D. C. Of this necessary advance, about 17 degrees was lag of injection behind pump cam timing. The injection interval for the pump stroke necessary to obtain 22 B. HP., when using the 0.018-inch orifice, was found from spray patterns to be 73 degrees. Consequently, injection occurred for 29 degrees after T. D. C. For the fuel quantity necessary to obtain 20 B. HP., the injection interval was 55 degrees, so that fuel was injected for 11 degrees after T. D. C. The low power output and the high fuel consumption with the plain nozzles indicated that good distribution of the fuel throughout the air charge and fine atomization were not being obtained. Also, inspection of the cylinder showed that fuel was being deposited on the combustion chamber wall opposite the injection valve, indicating too much penetration.

Following the tests with the plain nozzles, the lipped nozzle was adopted with a view to securing better atomization and distribution of the fuel with less penetration With this type nozzle it was found that deposition of fuel on the combustion chamber wall was reduced, the power output was increased and the fuel consumption lowered. The outstanding results obtained with this type nozzle are given in Table I, and are referred to in the following discussion. These tests were not continued until definite conclusions, as regards the interrelation and influence of the several variables on the engine performance could be made, as it was evident that a prolonged investigation with this cylinder would be inadvisable

MAXIMUM POWER

The maximum power developed during the tests using the lipped nozzle was 29.7 B. HP. at 1,700 R. P. M., or about 131 pounds I. M. E. P., run No. 138. Other high-power runs gave 29.1 B. HP. at 1,820 R. P. M., No. 147, and 28.3 B. HP. at 1,800 R. P. M., No. 148. The above runs were of short duration, being sustained only long enough to ensure a steady torque, in order to favor the piston as much as possible. During the longest run maintaining high power, No. 39, 25.2 B. HP. was developed for about 10 minutes. These tests were made with light alloy pistons. With a cast-iron piston, a maximum output of 21.8 B. HP. at 1,500 R. P. M. was obtained, No. 131. Because of the excessive weight of the cast-iron pistons, the engine speed was arbitrarily limited to 1,500 R. P. M. In order to obtain maximum power it was found necessary to advance the pump timing as much as 84 degrees before T. D. C. In each of the above runs, after reaching the above stated maximum power, further increase in the amount of fuel supplied had no noticeable effect on the torque. Attempts to obtain maximum power usually resulted in failure of the piston, either from burning of the head or cracking of the wrist-pin bosses.

The reason for the failure to approach more nearly the power output of this cylinder obtained when using carburetor has been attributed in part to the unsuitable form of combustion chamber. (Fig. 11.)


Depression in head to accommodate jet
Injection valve
Gasket
High compression piston 11.4 ratio
Standard army type piston 5.4 ratio

Piston at T.D.C.　　Piston 50 degrees before T.D.C.

FIG. 11.—Single-cylinder Liberty engine form of combustion chamber

FRICTION POWER

The friction horsepower of the engine, when using the high compression pistons, was somewhat higher than that obtained with the standard Liberty piston. The friction varied for the several pistons used, and was sensitive to changes in jacket water and oil temperatures. In computing indicated power, it was endeavored to obtain a value for friction power taken under conditions simulating those existing during the respective power runs.

FUEL CONSUMPTION

Best fuel economy was obtained when developing only 12 to 15 B. HP., or less than one-half the normal output of this cylinder when using a carburetor. Run No. 112 gave a fuel consumption with Diesel engine fuel oil of 0.47 pound per B. HP. hour, and run No. 111 gave 0.49 pound per B. HP. hour, the indicated specific fuel consumption being about 0.30 pound per I. HP. hour, in both cases.

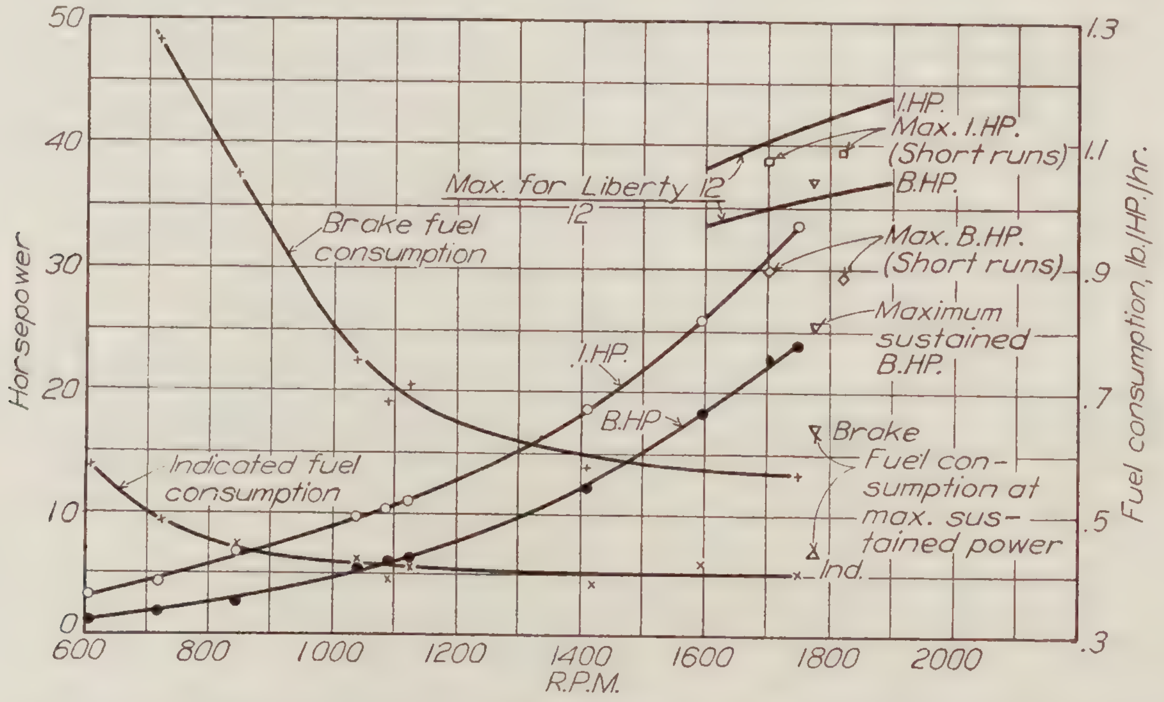


FIG. 12.—Single-cylinder Liberty engine compression ignition. Power and fuel consumption at part loads. Propeller load: 24 B. HP. at 1,750 R. P. M. taken as normal. Lipped nozzle with 0.018-inch diameter hole. Diesel engine fuel oil. 11.4 compression ratio

The specific fuel consumption increased with increase in power output above 15 B. HP. as shown in run No. 114, which gave a fuel consumption of 0.52 pound per B. HP. hour, when developing about 21 B. HP. at 1,750 R. P. M. under conditions directly comparable to those existing in run No. 112. The fuel consumption for the highest sustained power run No. 39, was about 0.64 pound per B. HP. hour showing again that increased power was obtained at the expense of fuel economy.

Part load runs were made for the purpose of determining fuel consumption over a wide range of loads. Table I gives the data for these runs, Nos. 42 to 60. A value of 24 B. HP. at 1,750 R. P. M. was taken arbitrarily as normal power and a series of runs made at an approximately constant speed of 1,740 R. P. M. with varying torque, and at varying speeds and torque corresponding to a propeller load. In the latter runs, data for which are plotted on Figure 12, the speed was varied as the cube root of the power, and the torque adjusted to give the required power at this speed. Test points for maximum power obtained, Nos. 138 and 147, and for maximum sustained power, No. 39, are plotted on this figure; the power developed in one cylinder of a Liberty 12 engine using carburetor is also shown. The specific fuel consumptions obtained during these series of part load runs were not as low as obtained during some other runs at the same load. However, all data for the part load runs were taken under the same engine conditions, except for variations in jacket water and oil temperatures, so that the results obtained during the individual runs of the part load series are comparable. The curves of specific fuel consumption against power for the series of part load runs at constant speed, shown on Figure 13, indicate that the consumption increased with power, the best economy being obtained at 12 B. HP. output. It can be seen that the fuel consumption for 24 B. HP. is lower than would be expected from the trend of the curves. This run was made some time before the other runs of the series, and the apparent discrepancy may have been due to conditions within the engine changing in the interim.

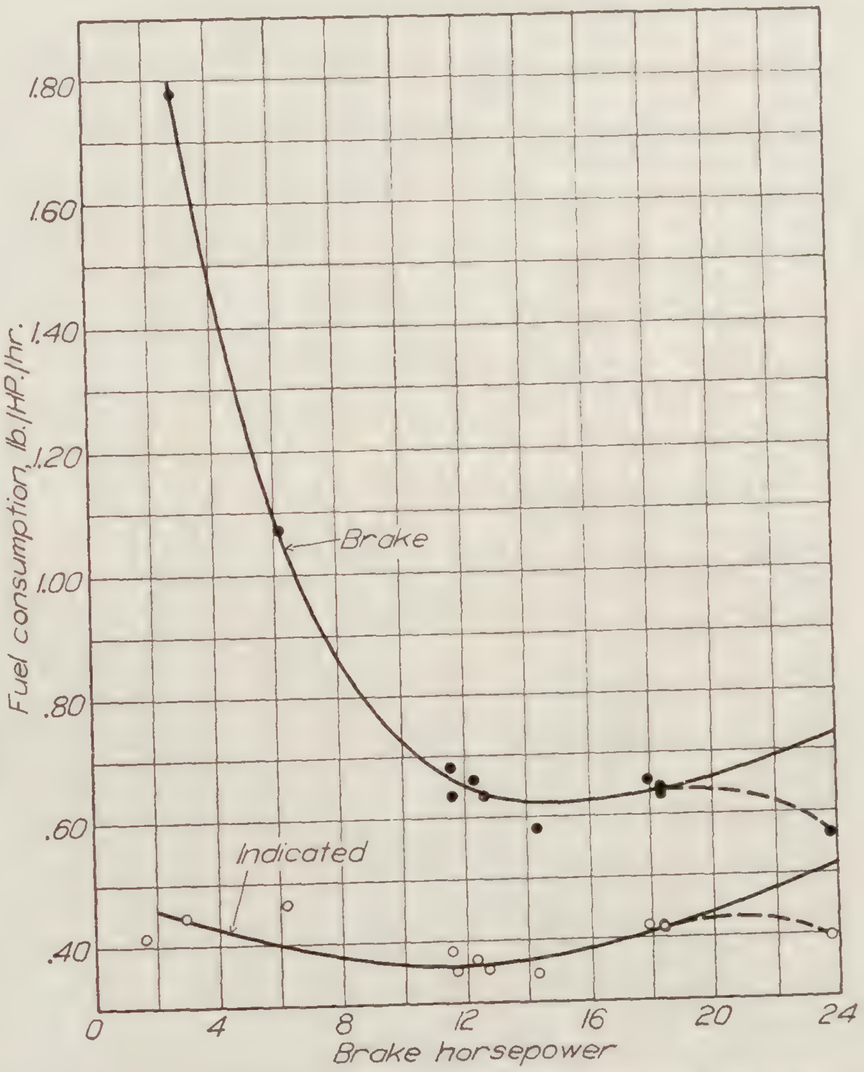


FIG. 13.—Single-cylinder Liberty engine compression ignition. Fuel consumption at part loads. Constant speed. Average speed, 1,740 R. P. M. Lipped nozzle with 0.018-inch diameter hole. Diesel engine fuel oil. 11.4 compression ratio

Tests were made to determine the variation, if any, in fuel consumption during a run of appreciable duration maintaining constant power output. In run No. 116, 16.3 B. HP. at 1,740 R. P. M. was held for approximately one hour, during which the average fuel consumption was 0.51 pound per B. HP. hour with not more than a 3 per cent variation during any of the 7-minute intervals when the rate of fuel flow was timed. In run No. 130, using a cast-iron piston, 16 B. HP. at 1,520 R. P. M. was maintained for nearly 2 hours with an average fuel consumption of 0.66 pound per B. HP. hour. The specific brake fuel consumption for the first 6-minute interval was 0.69 pound, and for the last time interval was 0.66 pound; the lowest consumption during any time interval being 0.65 pound. During run No. 116 the aluminum alloy piston No. 4 failed, due to burning of the head; and during run No. 130 the cast-iron piston No. 7 failed, due to cracking of the wrist pin bosses.

Runs No. 40 and 41 give comparative power and fuel consumption figures for the engine operating under the same conditions with kerosene and with Diesel engine fuel oil. These two runs were made without stopping the engine, the change in fuel being effected while under power. Diesel engine fuel oil gave a lower specific fuel consumption and higher power.

Tests with the lipped nozzle to determine the effect of nozzle orifice diameter on specific fuel consumption showed that best economy was obtained with a 0.014-inch orifice. Decreasing the orifice diameter still further, to 0.012 inch, increased the fuel consumption due, probably to the longer interval of injection with the smaller orifice. The 0.014-inch orifice was, apparently, a good compromise between the somewhat finer atomization obtained with a small orifice and the shorter interval of injection with a large orifice.

FLEXIBILITY

The engine could be idled smoothly at 400 R. P. M. when using Diesel engine fuel oil, and at 630 R. P. M. when using kerosene. The acceleration under load was not satisfactory as compared with the carbureted engine due, in part, to the fact that injection timing could not be varied when the engine was running.

STARTING CONDITIONS

No difficulty was experienced in starting with compression ignition only, when the compression pressure was over 300 pounds and the jacket water temperature about 100° F. With lower compression pressures, it was found necessary to employ some auxiliary means for starting; and it was desirable not to use spark ignition. The engine could be started by increasing the jacket water or inlet air temperature or by increasing the compression pressure through increasing the initial pressure. Heating the jacket water caused delay and, besides, was least effective in facilitating starting. Heating the inlet air was very effective but necessitated the use of some form of heater. However, it was found that the engine could be started, with jacket water and inlet air at room temperature, simply by attaching a long pipe to the intake, thus obtaining an increase in compression pressure. (Reference 2.) In order to realize the advantages of this method, it was necessary to motor the engine at fairly high speeds. By using a suitable length of pipe for a given engine speed the compression pressure was increased as much as 17 per cent. Figure 14 shows the increase in compression pressure, as measured by the Okill gauge, that was obtained by using the long intake pipe.

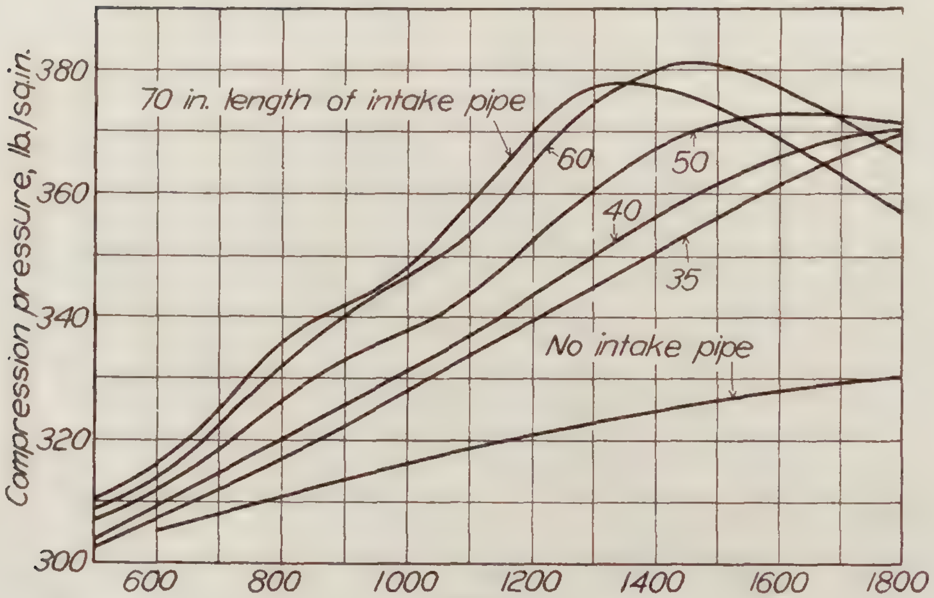


FIG. 14.—Single-cylinder Liberty engine. Increase in compression pressure obtained with long intake pipe. Pipe 3 inches diameter

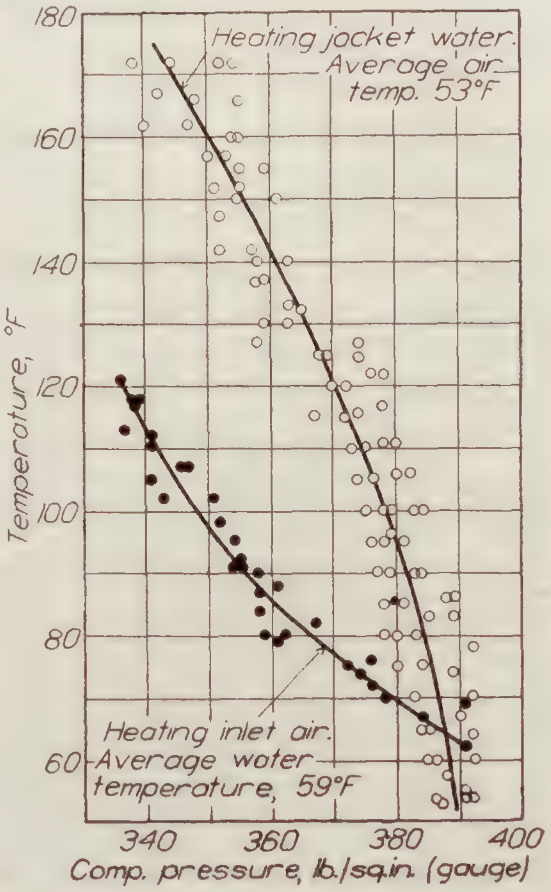


FIG. 15.—Single-cylinder Liberty engine compression ignition. Starting condition. Lipped nozzle with 0.014-inch diameter hole. Diesel engine fuel oil. 11.4 compression ratio

With a constant compression ratio, and using a long intake pipe to obtain variation in compression pressure, a short investigation was made to determine the relation between jacket water temperature, with inlet air at room temperature, and inlet air temperature, with jacket water at room temperature, and the compression pressure at which the engine would start firing. (Reference 3.) The results are plotted on Figure 15.

These starting tests indicate the sensitiveness of this compression ignition engine to changes in final compression pressure, with constant compression ratio and, further, suggest the need for providing some means, such as supercharging, to compensate for the reduced air pressures and temperatures that would be encountered when operating at high altitudes, in order to insure reliable operation.

MAXIMUM PRESSURES

Excessively high maximum combustion pressures were encountered during this investigation. Records taken with a Mader microindicator, indicated maximum pressures of the order of 1,600 pounds per square inch; and a spring-loaded relief valve, located in the second spark plug hole and set to open at 1,300-pound gauge pressure, "popped" regularly when the engine was developing only moderate torque, about 60 pounds B. M. E. P.

Antiknock dopes, and cooled exhaust gases introduced with the entering air charge were tried in an attempt to reduce these high maximum pressures but, although somewhat smoother running and a slight increase in power output for given engine settings were obtained, maximum pressures were not reduced appreciably. The doped fuels tried consisted of fuel oil and 5 per cent by volume of aromatic amines, and fuel oil and 0.3 per cent by volume of tetra-ethyl lead. An increase in power was obtained by directing a jet of exhaust gases, cooled to 110° F., into the engine intake through a section of ½-inch pipe, but further investigation indicated that this increase in power may have been due to the increased turbulence resulting from directing the jet into the intake rather than to smoother combustion resulting from using the exhaust gases as a diluent.

EFFECT OF TURBULENCE ON POWER

While experimenting with exhaust gases introduced into the engine intake through a small pipe, it was found that variations in power occurred when the jet of gases was directed toward different parts of the intake. The injection valve was located to the left of the intake opening and nearly in the same horizontal plane. Directing the jet toward the right side of the intake, or away from the injection valve, gave no increase in torque or speed, but directing the jet to the left, or toward the injection valve, gave an appreciable increase in torque and speed. In one test, while developing about 11 B. HP. at 1,650 R. P. M., the torque and speed were both increased about 10 per cent when the jet of exhaust gases was directed toward the injection valve. The increase in power thus obtained was attributed to the increased turbulence in the vicinity of the injection valve. However, another explanation might be that, supposing combustion to start in the vicinity of the injection valve, directing the jet toward the injection valve may have resulted in placing the inert gases in that part of the combustion chamber where they could be most effective in acting as a diluent, thus slowing up the rate of burning of the portion of the combustible mixture first ignited, whereas, directing the jet away from the injection valve may have resulted in preventing the inert gases from coming into the region where ignition first occurred.

A further investigation of the effect of turbulence was made by using a throttled inlet port. A metal plate, that covered all but a 90° sector of the intake opening, was clamped over the intake. When the opening was changed from the lower right position to the lower left position an increase in torque of about 9 per cent and an increase in speed of about 13 per cent was obtained.

A further study of the effect of the direction of the entering air stream on power and fuel consumption was not made, but such an investigation, with a more suitable cylinder, might be profitable.

FUEL PUMP CHARACTERISTICS (Reference 4)

An investigation of the spring-actuated fuel pump was made, using the spray pattern method previously described, to determine the effect on the lag and interval of injection, of injection valve orifice size, injection valve opening pressure and fuel pump stroke, or fuel quantity. Spray patterns were taken, with the engine motored at a constant speed of 1,600 R. P. M., for nozzle orifices 0.012, 0.014, 0.018, and 0.022 inch in diameter, for opening pressures of 2,200, 3,200, and 5,000 pounds per square inch and for varying fuel quantities. The results obtained with three sizes of nozzle orifice are shown on Figures 16, 17, and 18. Figure 19 is a cross plot showing the effect of orifice diameter on lag and interval of injection for one opening pressure and pump stroke. Although somewhat erratic, due to the difficulty experienced in defining the beginning and ending of the spray pattern, the results show, in general that:

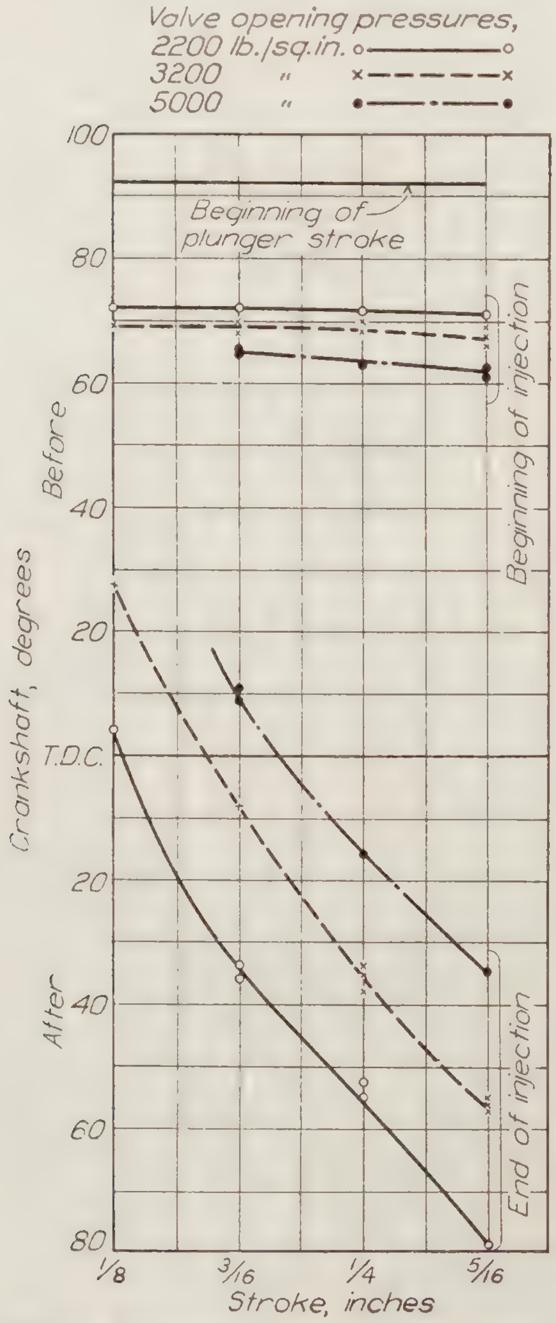


FIG. 16.—Lipped nozzle with 0.012-inch diameter hole

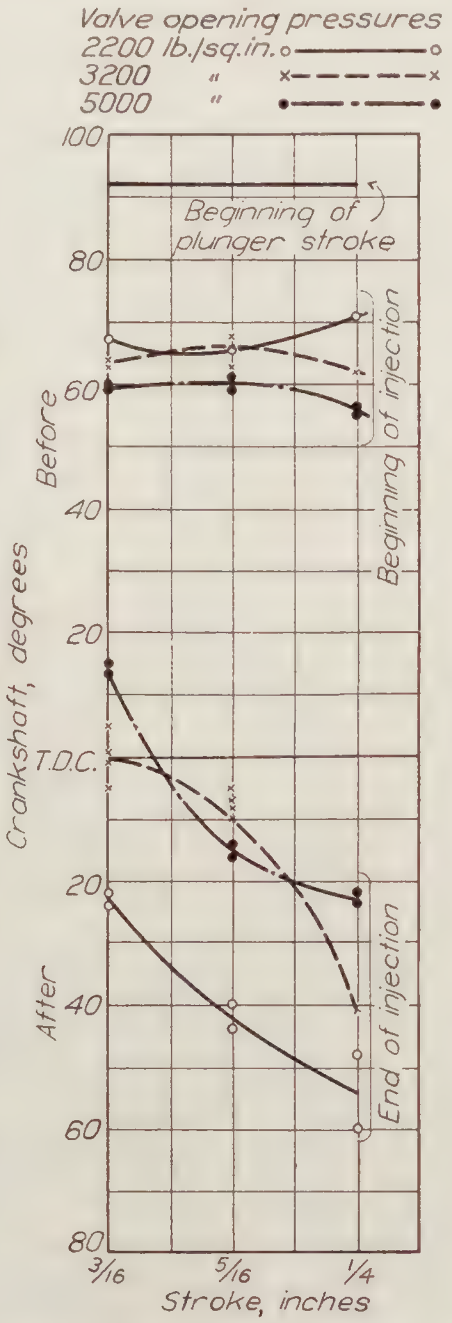


FIG. 17.—Lipped nozzle with 0.014-inch diameter hole

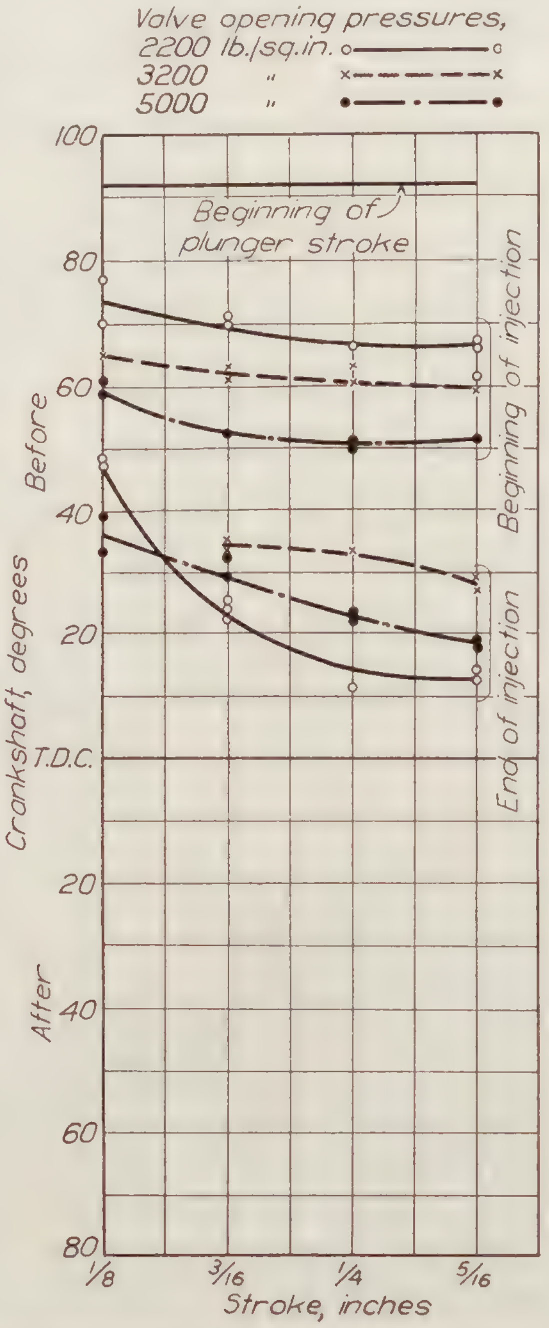


FIG. 18.—Lipped nozzle with 0.018 inch diameter hole

Characteristics of spring actuated fuel pump. Effect of pump stroke and valve opening pressure on lag and interval of injection. Diesel engine fuel oil. R. P. M., 1,600

> Lag increases with increase in orifice size, injection valve opening pressure, and pump stroke. Interval of injection decreases with increase in orifice size and opening pressure, and with decrease in pump stroke.

Distribution of fuel on the spray patterns indicated, in some cases, that the injection valve stem rebounded from its seat once or twice during a single injection. The above information can not be used in determining the lag and interval of injection for the power runs given in Table I, as data on opening pressure and pump stroke were not definitely determined during these power runs.

The spring-actuated injection pump, for given conditions, gives an approximately constant interval of injection, in terms of absolute time, independent of engine speed. When measured in degrees of crank travel, however, the injection interval varies directly with engine speed.

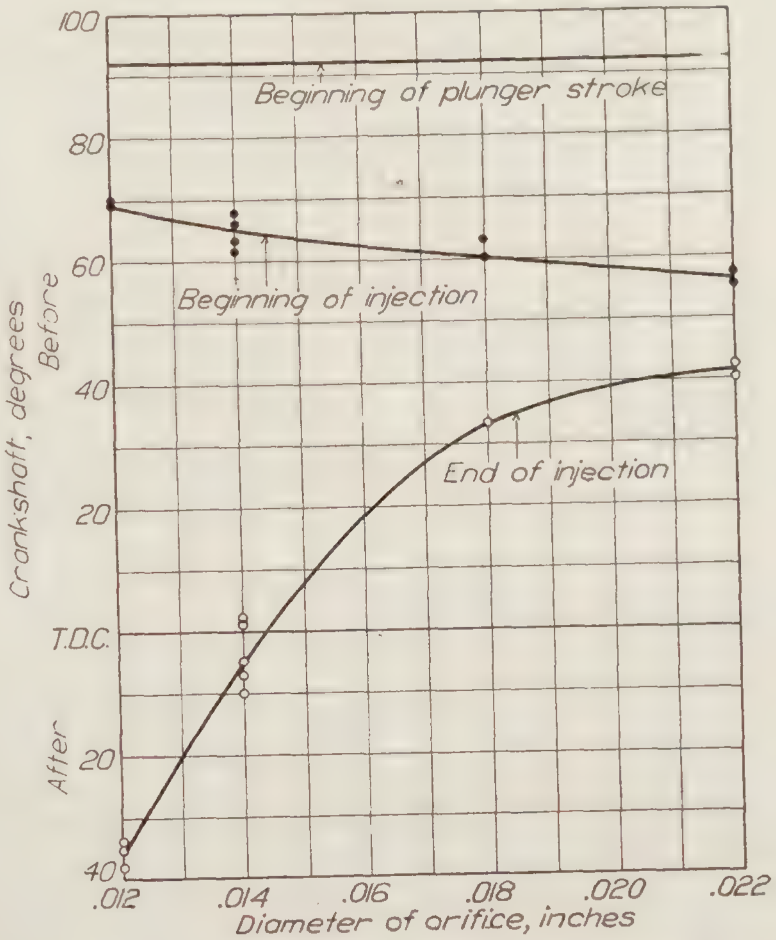


FIG. 19.—Injection-valve opening pressure, 3,200 pounds. Pump stroke, ¼ inch. R. P. M., 1,600. Characteristics of spring-actuated fuel pump. Effect of orifice size on lag and interval of injection

CONCLUSIONS

The results obtained during this investigation can be used only as a general indication of the possibilities of, and the difficulties to be overcome in applying airless injection with compression ignition to aircraft engines. The combustion chamber of the Liberty cylinder was not suitable for compression ignition research, and probably accentuated the difficulties encountered in attempting to obtain high mean effective pressures.

It appears that a reasonably low fuel consumption can be obtained at reduced loads, as it was possible, with an unfavorable form of combustion chamber, to obtain an indicated specific fuel consumption as low as 0.30 pound per I. HP. hour when developing about 16 B. HP. at 1,730 R. P. M. With this engine, specific fuel consumption increased materially with power output above 16 B. HP. at these speeds. The maximum power output obtained, 29.7 B. HP. at 1,700 R. P. M., may be considered encouraging in view of the unsuitable combustion chamber in which good distribution of the fuel could not be obtained. However, high power output could be maintained for only very short periods of time due to piston failure. Excessive exposed area of the piston to combustion temperature accentuated piston trouble. No difficulty was experienced in metering and injecting the small quantities of fuel required when operating at engine speeds as high as 1,850 R. P. M. The extreme injection advance found necessary accounts in part for the high maximum combustion pressures encountered, as practically the entire fuel charge was in the cylinder at the time ignition occurred, so that constant volume combustion of most of the fuel charge resulted. This indicates the need for reducing the lag of ignition to a minimum, in order to obviate the need for extremely early injection. The brief tests indicating the effect of turbulence on power may be considered valuable in pointing out what may be obtained on this score. The tests showing the sensitiveness of compression ignition to changes in temperature and pressure of the induced air indicate clearly the need for supercharging in order to obtain reliable engine operation at altitude.

REFERENCES

The information given in References 2, 3, and 4 was obtained during the present investigation, but has been previously reported.

1. H. Moss and W. J. Stern____________________ Mechanical Efficiency of an Internal Combustion Engine. From "Automobile Engineer" (Eng.) March, 1925.
2. Robertson Matthews and Arthur W. Gardiner_ Increasing the Compression Pressure in an Engine by Using a Long Intake Pipe. N. A. C. A. Technical Note No. 180–1924.
3. Robertson Matthews and Arthur W. Gardiner_ The Influence of Inlet Air Temperature and Jacket Water Temperature on Initiating Combustion in a High-Speed Compression Ignition Engine. N. A. C. A. Technical Note No. 185–1924.
4. Robertson Matthews and Arthur W. Gardiner_ The Time Lag and Interval of Discharge with a Spring-Actuated Fuel Injection Pump. N. A. C. A. Technical Note No. 159–1923.

TABLE I

TEST RESULTS. RUNS WITH LIPPED NOZZLE INJECTION VALVE AND DIESEL ENGINE FUEL OIL

Run No.	Piston No.	Duration, minutes	R. P. M.	B. H P.	F. HP.	I. HP.	B. M. E. P., lb./sq. in.	I. M. E. P., lb./sq. in.	Mechanical efficiency, per cent	Fuel consumption, lb./B. HP. hr.	Fuel consumption, lb./I. HP. hr.	Nozzle orifice diameter, in.	Fuel pump timing deg. before T. D. C.[1]	Water out temperature, ° F.	Oil out temperature, ° F.
32	2	10	1,743	19.5	10.0	29.5	64.5	96	66	0.601	0.397	0.018	74	140	60
39	2	10	1,779	25.2	10.3	35.5	81.6	115	71	.637	.452	.018	74	145	58
40	3	12	1,724	21.2	10.4	31.6	71.0	106	67	.596	.400	.018	74	140	122
41	3	12	1,750	23.7	10.6	34.3	78.1	113	69	.566	.391	.018	74	140	121
42	3	34	608	1.17	2.1	3.27	11.0	31	36	1.620	.580	.018	60	170	116
43	3	16	1,040	5.44	4.1	9.54	30.2	53	57	.750	.428	.018	60	170	116
44	3	20	846	2.86	3.8	6.66	19.4	45	43	1.050	.451	.018	60	176	101
45	3	9	1,410	12.2	6.2	18.4	49.9	75	66	.578	.382	.018	53	168	121
46	3	5	1,595	18.1	7.8	25.9	65.5	94	70	.60	.419	.018	60	158	122
47	3	16	1,090	5.9	4.4	10.3	31.2	54	57	.682	.391	.018	60	152	121
48	3	15	1,124	6.15	4.5	10.65	31.6	55	58	.710	.410	.018	53	166	121
49	3	15	720	1.62	2.6	4.22	13.0	34	38	1.270	.488	.018	53	165	119
50	3	7	1,730	2.98	9.0	11.98	9.9	40	25	1.78	.443	.018	67	169	132
51	3	10	1,745	6.2	9.3	15.5	20.5	51	40	1.07	.466	.108	67	168	120
52	3	8	1,680	11.56	9.0	20.56	39.7	70	56	.686	.386	.018	67	156	112
53	3	8	1,760	12.6	10.0	22.6	41.2	74	56	.635	.355	.018	60	153	120
55	3	9	1,740	11.6	9.7	21.3	38.4	70	54	.642	.349	.018	67	141	125
56	3	8	1,725	12.3	9.8	22.1	41.3	74	56	.660	.368	.018	67	135	123
57	3	6	1,760	17.9	10.0	27.9	58.7	91	64	.655	.421	.018	60	145	120
58	3	6	1,760	18.3	9.8	28.1	59.9	92	65	.646	.420	.018	60	155	122
59	3	6	1,753	18.3	9.5	27.8	60.1	91	66	.638	.420	.018	60	162	124
60	3	14	1,749	1.62	9.3	10.92	5.35	36	15	2.82	.418	.018	60	170	126
111	4	10	1,722	13.6	8.7	22.3	45.5	75	61	.488	.298	.014	77	120	105
112	4	9	1,731	15.7	8.8	24.5	52.3	82	64	.471	.302	.014	77	123	115
114	4	6	1,748	20.8	9.0	29.8	68.5	98	70	.524	.366	.014	77	120	123
116	4	59	1,737	16.3	8.9	25.2	54.4	84	65	.510	.330	.014	77	120	124
130	7	114	1,516	16.0	7.1	23.1	60.7	88	69	.662	.458	.014	77	100	128
131	8	2	1,500	21.8	7.0	29.8	83.6	115	73	--------	--------	.022	77	120	112
138	12	½	1,700	29.7	9.0	38.7	101.	131	77	--------	--------	.018	77	125	110
147	14	½	1,820	29.1	10.2	39.3	92.4	125	74	--------	--------	.026	84	140	--------
148	14	1	1,800	28.3	10.0	38.3	90.9	123	74	--------	--------	.026	84	140	--------

[1] Fuel pump cam setting. Time when fuel enters cylinder not given.

Pistons 2, 3, and 4 aluminum alloy; pistons 7 and 8 cast iron; pistons 12 and 14 magnesium alloy.
Primary pump pressures up to 250 pounds. Injection valve opening pressures from 1,200 to 5,400 pounds.
Run 39, maximum sustained power; cracked water jacket during run.
Run 40, kerosene fuel used.
Run 112, best fuel economy.
Run 116, injection nozzle clean at end of run; failure of piston.
Run 130, injection nozzle clean at end of run; failure of piston.
Run 131, piston bosses cracked during run.
Run 138, maximum power, piston bosses cracked during run.

REPORT No. 244

AERODYNAMIC CHARACTERISTICS OF AIRFOILS—IV

CONTINUATION OF REPORTS NOS. 93, 124, AND 182

By

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

REPORT No. 244

AERODYNAMIC CHARACTERISTICS OF AIRFOILS—IV

CONTINUATION OF REPORTS NOS. 93, 124, AND 182

By The National Advisory Committee for Aeronautics

INTRODUCTION

This collection of data on airfoils has been made from the published reports of a number of the leading aerodynamic laboratories of this country and Europe.[1] The information which was originally expressed according to the different customs of the several laboratories is here presented in a uniform series of charts and tables suitable for the use of designing engineers and for purposes of general reference.

It is a well-known fact that the results obtained in different laboratories, because of their individual methods of testing, are not strictly comparable even if proper scale corrections for size of model and speed of test are supplied. It is, therefore, unwise to compare too closely the coefficients of two wing sections tested in different laboratories. Tests of different wing sections from the same source, however, may be relied on to give true relative values.

The series of airfoils designated N. A. C. A.–M1 to N. A. C. A.–M27 (Reference Nos. 506 to 532) were tested in the variable density wind tunnel of the National Advisory Committee for Aeronautics at a pressure of approximately 20 atmospheres.

The absolute system of coefficients has been used, since it is thought by the National Advisory Committee for Aeronautics that this system is the one most suited for international use and yet it is one from which a desired transformation can be easily made. For this purpose a set of transformation constants is given.

Each airfoil section is given a reference number, and the test data are presented in the form of curves from which the coefficients can be read with sufficient accuracy for designing purposes. The dimensions of the profile of each section are given at various stations along the chord in per cent of the chord, the latter also serving as the datum line. When two sets of ordinates are necessary, on account of taper in chord or ordinate, those for the maximum section (at center of span) are given on the individual characteristic sheets, while those for the tip (dotted) section are given in separate tables, page 226. Where the ratio of ordinate to chord remains constant the one set of ordinates applies to both center and tip section. The shape of the section is also shown with reasonable accuracy to enable one to more clearly visualize the section under consideration, together with its characteristics.

The authority for the results here presented is given as the name of the laboratory at which the experiments were conducted, with the size of model, wind velocity, and year of test.

TRANSFORMATION CONSTANTS

For the convenience of those who prefer to use a system of units other than the absolute system, there is given below a table of transformation constants based on the standard condition adopted by the National Advisory Committee for Aeronautics of—

Temperature = 15.6° C. = 60.1° F.
Pressure = 760 mm Hg. = 29.92 in. Hg.
Humidity = 0.
Gravity = 9.806 m/sec.^{2} = 32.172 ft./sec.^{2}

---

[1] A previous collection of airfoil sections 1 to 503 and charts 1 to 12 may be found in N. A. C. A. Reports Nos. 93, 124, and 182.

thus giving values of specific weight of air

$$W = 1.223 \text{ kg/m}^3 = 0.07635 \text{ lb./ft.}^3$$

and of density

ρ = 0.1247 in the French engineering or kilogram, meter, second system.

Or

= 0.00237 in the English or pound, foot, second system.

In absolute units	$P = CV^2\rho/2$
In kg/m ^{2} (m/sec.)	$P = .0625\ CV^2$
In kg/m ^{2} (km/hr.)	$P = .004822\ CV^2$
In lb./sq. ft. (ft./sec.)	$P = .001189\ CV^2$
In lb./sq. ft. (mi./hr.)	$P = .002558\ CV^2$

Note that these constants are half as large as those used in Reports Nos. 93 and 124 and that the absolute coefficients used in this report are twice as large as the old coefficients. See Report No. 240 regarding change in absolute coefficients.)

INDEX

Three separate types of index are given—chart indexes which make it possible for a designer to select the wing section most suitable for the particular design in which he is interested; a group index which is arranged by countries and laboratories at which tests were conducted, each section also being designated by a reference number; and an alphabetical index.

CHART INDEX

In order that the designer may easily pick out a wing section which is suited to the type of airplane on which he is working, four index charts are given which classify the wings according to their aerodynamic and structural properties. In the charts of this report a lower-case letter is placed adjacent to the reference number giving Vl values, so that a comparison can be made without referring to the individual drawings. In this value V represents wind velocity in feet per second and l a linear dimension, the chord, in feet.

In chart No. 13 the minimum drag, C_D is plotted against the L/D at one-fourth the maximum lift, C_L. This chart should be used in choosing a wing section for a high-speed airplane, the wing sections being more suited for this use the farther they are from the lower left-hand corner.

In chart No. 14 the mean spar depth is plotted against the maximum lift, C_L in order to show the possible strength and lightness of the wing structure. The higher the maximum lift coefficient is the smaller will be the wing area and the lighter the structural weight, and in the same way the greater the depth of the spars the lighter will be their weight, so that the sections the greatest distance from the lower left-hand corner will give the lightest and strongest wings. The "mean spar depth" is obtained by assuming the spars to be located respectively at 15 and 60 per cent of the chord, and by dividing the sum of their thicknesses by 2. In the case of sections tapered in ordinate, or chord, or both, the mean spar depth of the maximum section (section at center of span) is taken in per cent of the constant chord for the ordinate taper, and of the mean chord for the chord taper although accompanied, in certain airfoils, with an ordinate taper.

In chart No. 15 the maximum L/D is plotted against the maximum lift, C_L, which is of use in choosing the wing section for a slow and efficient airplane. In the same way as before the sections farthest from the lower left-hand corner are the best for this purpose.

In chart No. 16 the L/D at two-thirds the maximum lift, C_L is plotted against the maximum lift, C_L. This chart can be used for choosing a section that will give an efficient climb or a long range at cruising speed. The best sections for this purpose will be farthest from the lower left-hand corner of the chart.

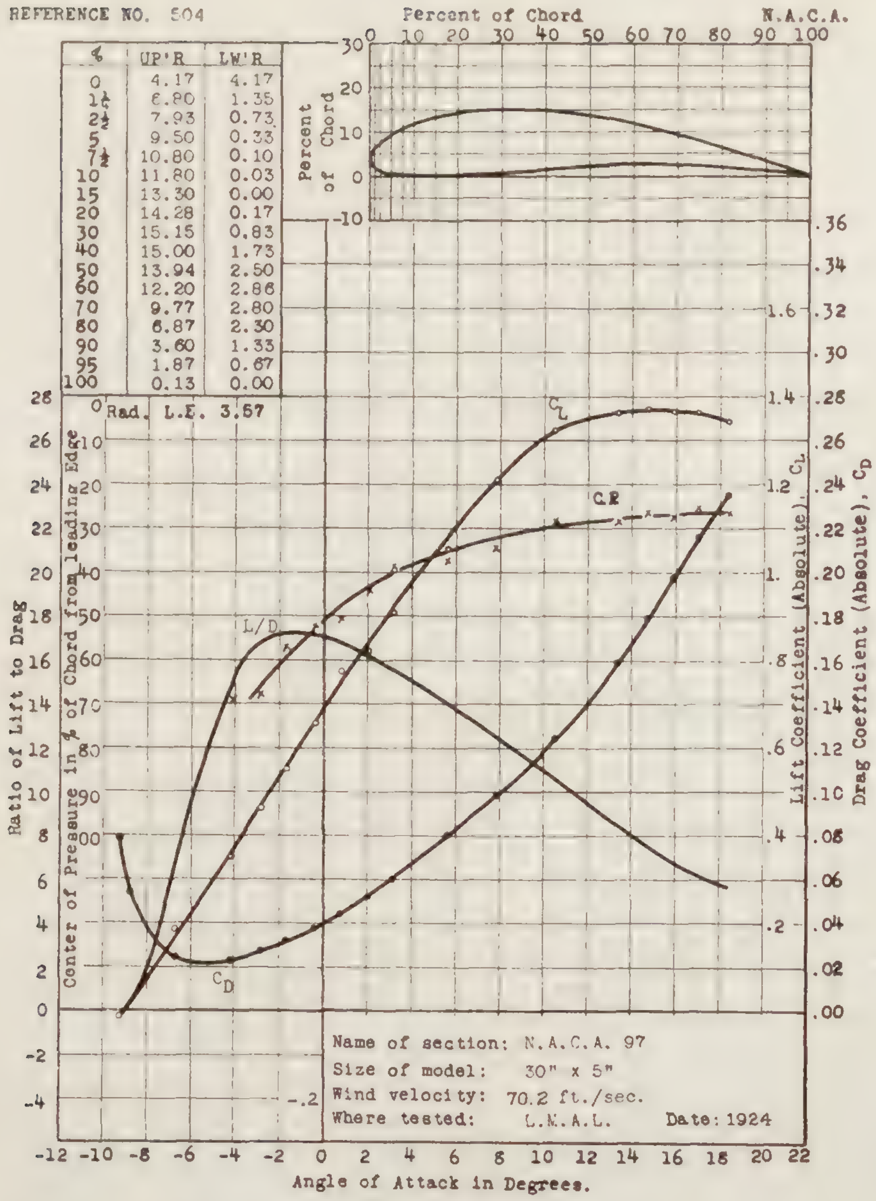
GROUP INDEX

Airfoil	Wind tunnel	Report reference number
UNITED STATES		
N. A. C. A. 97	L. M. A. L.	504
N. A. C. A. 98	do	505
N. A. C. A.–M1	do	506
N. A. C. A.–M2	do	507
N. A. C. A.–M3	do	508
N. A. C. A.–M4	do	509
N. A. C. A.–M5	do	510
N. A. C. A.–M6	do	511
N. A. C. A.–M7	do	512
N. A. C. A.–M8	do	513
N. A. C. A.–M9	do	514
N. A. C. A.–M10	do	515
N. A. C. A.–M11	do	516
N. A. C. A.–M12	do	517
N. A. C. A.–M13	do	518
N. A. C. A.–M14	do	519
N. A. C. A.–M15	do	520
N. A. C. A.–M16	do	521
N. A. C. A.–M17	do	522
N. A. C. A.–M18	do	523
N. A. C. A.–M19	do	524
N. A. C. A.–M20	do	525
N. A. C. A.–M21	do	526
N. A. C. A.–M22	do	527
N. A. C. A.–M23	do	528
N. A. C. A.–M24	do	529
N. A. C. A.–M25	do	530
N. A. C. A.–M26	do	531
N. A. C. A.–M27	do	532
U. S. A. 5	do	533
U. S. A. 27	do	534
U. S. A. 35A	do	535
U. S. A. 35B	do	536
U. S. A. 27 with ordinates decreased 10 per cent	W. N. Y.	539
Albatross (Modified) A	do	540
Albatross (Modified) B	do	541
C–62	do	542
TX	do	543
D–2 (Modified M–80)	do	544
Göttingen 387 (Tapered)	do	545
N. W.	do	546
Dayton-Wright T–1	do	547
Dayton-Wright T–1 (Tapered)	do	548
NS–1	do	549
DW–9	do	550
N–6	do	551
N–7	do	552
N–8	do	553
N–9	do	554
N–10	do	555
N–11	do	556
N–12	do	557
N–13	do	558
N–14	do	559
N–15	do	560
N–16	do	561
N–17	do	562
N–18	do	563
N–19	do	564
N–20	do	565
Sloane (Modified)	do	566
U. S. A. 40	McC F.	567
U. S. A. 41	do	568
U. S. A. 46	do	569
U. S. A. 48	do	570
U. S. A. 49	McC F	571
U. S. A. 50	do	572
U. S. A. 51	do	573
R–3	do	574
Glenn Martin 2 (Modified)	M. I. T.	575
Dayton-Wright 5	do	576
Dayton-Wright 6	do	577
U. S. A. 35	do	578
U. S. A. 40B	do	579
U. S. A. 45	do	580
Clark V	do	581
Clark W	do	582
Clark X	do	583
Clark Y	do	584
Clark Z	do	585
C–27	do	586
Halbronn 1–A	do	587
Hill 85–15	do	588
Glenn Martin 7	Göttingen	589
Glenn Martin 9	do	590
Glenn Martin 11	do	591
Glenn Martin 13	do	592
Glenn Martin 15	do	593
Glenn Martin 16	do	594
Glenn Martin 17	do	595
Glenn Martin 18	do	596
Glenn Martin 19	do	597
Glenn Martin 20	do	598
Glenn Martin 21	do	599
GREAT BRITAIN		
Fage & Howard A	N. P. L.	600
Fage & Howard B	do	601
Fage & Howard C	do	602
Fage & Howard D	do	603
Fage & Howard E	do	604
Fage & Howard F	do	605
R. A. F. 15	L. M. A. L.	537
R. A. F. 30	R. A. E.	606
R. A. F. 31	do	607
R. A. F. 32	do	608
R. A. F. 33	do	609
GERMANY		
Göttingen 274 (Daimler V)	Göttingen	610
Göttingen 275 (Daimler VI)	do	611
Göttingen 276 (Daimler VII)	do	612
Göttingen 279 (Daimler X)	do	613
Göttingen 280 (Daimler XI)	do	614
Göttingen 282 (Daimler XIII)	do	615
Göttingen 308 (M. V. A. H. 40)	do	616
Göttingen 309 (M. V. A. H. 41)	do	617
Göttingen 310 (M. V. A. H. 42)	do	618
Göttingen 314 (Hansa-Brandenburg).	do	619
Göttingen 315 (Hansa-Brandenburg III.5).	do	620
Göttingen 316 (Hansa-Brandenburg IV.5).	do	621
Göttingen 318 (Hansa-Brandenburg VI.5).	do	622
Göttingen 326 (Pfalz 55)	do	623
Göttingen 387	L. M. A. L.	538

ALPHABETICAL INDEX

Airfoil	Report reference number
Albatross (modified) A	540
Albatross (modified) B	541
C–27	586
C–62	542
Clark V	581
Clark W	582
Clark X	583
Clark Y	584
Clark Z	585
D–2 (Modified M–80)	544
Dayton-Wright 5	576
Dayton-Wright 6	577
Dayton-Wright T–1	547
Dayton-Wright T–1 (tapered)	548
DW–9	550
Fage & Howard A	600
Fage & Howard B	601
Fage & Howard C	602
Fage & Howard D	603
Fage & Howard E	604
Fage & Howard F	605
Glenn Martin 2 (modified)	575
Glenn Martin 7	589
Glenn Martin 9	590
Glenn Martin 11	591
Glenn Martin 13	592
Glenn Martin 15	593
Glenn Martin 16	594
Glenn Martin 17	595
Glenn Martin 18	596
Glenn Martin 19	597
Glenn Martin 20	598
Glenn Martin 21	599
Göttingen 274 (Daimler V)	610
Göttingen 275 (Daimler VI)	611
Göttingen 276 (Daimler VII)	612
Göttingen 279 (Daimler X)	613
Göttingen 280 (Daimler XI)	614
Göttingen 282 (Daimler XIII)	615
Göttingen 308 (M. V. A. H. 40)	616
Göttingen 309 (M. V. A. H. 41)	617
Göttingen 310 (M. V. A. H. 42)	618
Göttingen 314 (Hansa-Brandenburg)	619
Göttingen 315 (Hansa-Brandenburg III.5)	620
Göttingen 316 (Hansa-Brandenburg IV.5)	621
Göttingen 318 (Hansa-Brandenburg VI.5)	622
Göttingen 326 (Pfalz 55)	623
Göttingen 387	538
Göttingen 387 (tapered)	545
Halbronn 1–A	587
Hill 85–15	588
N–6	551
N–7	552
N–8	553
N–9	554
N–10	555
N–11	556
N–12	557
N–13	558
N–14	559
N–15	560
N–16	561
N–17	562
N–18	563
N–19	564
N–20	565
N. A. C. A. 97	504
N. A. C. A. 98	505
N. A. C. A.–M1	506
N. A. C. A.–M2	507
N. A. C. A.–M3	508
N. A. C. A.–M4	509
N. A. C. A.–M5	510
N. A. C. A.–M6	511
N. A. C. A.–M7	512
N. A. C. A.–M8	513
N. A. C. A.–M9	514
N. A. C. A.–M10	515
N. A. C. A.–M11	516
N. A. C. A.–M12	517
N. A. C. A.–M13	518
N. A. C. A.–M14	519
N. A. C. A.–M15	520
N. A. C. A.–M16	521
N. A. C. A.–M17	522
N. A. C. A.–M18	523
N. A. C. A.–M19	524
N. A. C. A.–M20	525
N. A. C. A.–M21	526
N. A. C. A.–M22	527
N. A. C. A.–M23	528
N. A. C. A.–M24	529
N. A. C. A.–M25	530
N. A. C. A.–M26	531
N. A. C. A.–M27	532
NS–1	549
N. W	546
R–3	574
R. A. F. 15	537
R. A. F. 30	606
R. A. F. 31	607
R. A. F. 32	608
R. A. F. 33	609
Sloane (modified)	566
TX	543
U. S. A. 5	533
U. S. A. 27	534
U. S. A. 27 with ordinates decreased 10 per cent	539
U. S. A. 35	578
U. S. A. 35A	535
U. S. A. 35B	536
U. S. A. 40	567
U. S. A. 40B	579
U. S. A. 41	568
U. S. A. 45	580
U. S. A. 46	569
U. S. A. 48	570
U. S. A. 49	571
U. S. A. 50	572
U. S. A. 51	573

REFERENCE NO. 504

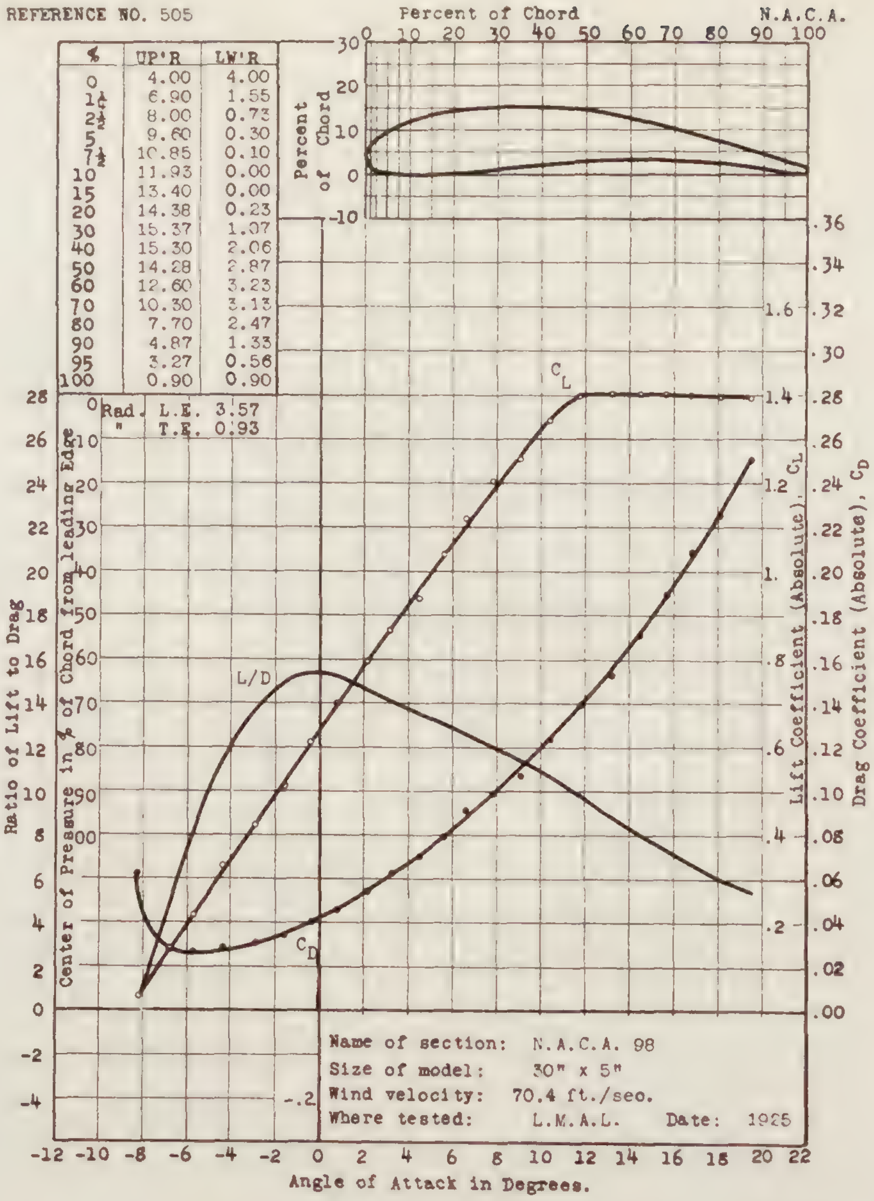


%	UP'R	LW'R
0	4.17	4.17
1¼	6.80	1.35
2½	7.93	0.73
5	9.50	0.33
7½	10.80	0.10
10	11.80	0.03
15	13.30	0.00
20	14.28	0.17
30	15.15	0.83
40	15.00	1.73
50	13.94	2.50
60	12.20	2.86
70	9.77	2.80
80	6.87	2.30
90	3.60	1.33
95	1.87	0.67
100	0.13	0.00

Rad. L.E. 3.57

Name of section: N.A.C.A. 97
Size of model: 30" x 5"
Wind velocity: 70.2 ft./sec.
Where tested: L.M.A.L. Date: 1924

REFERENCE NO. 505

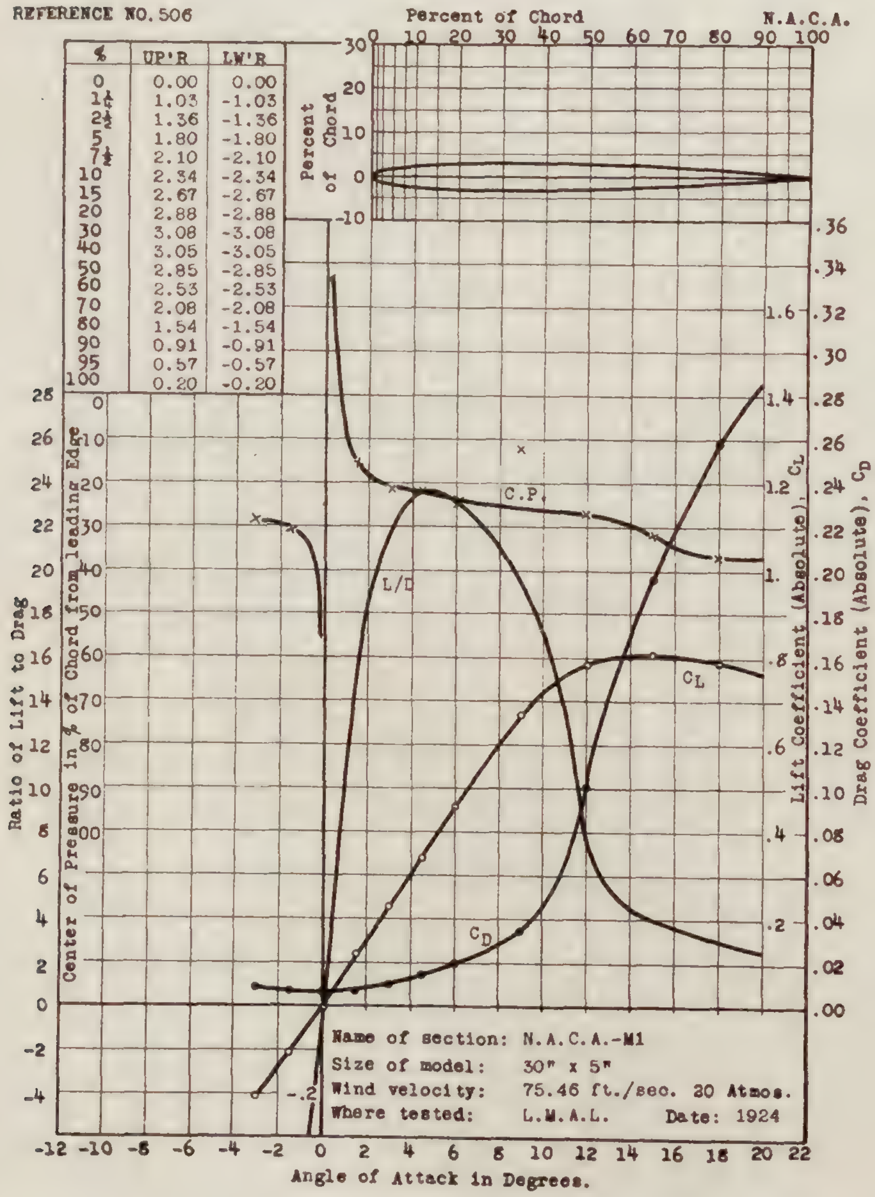


%	UP'R	LW'R
0	4.00	4.00
1¼	6.90	1.55
2½	8.00	0.73
5	9.60	0.30
7½	10.85	0.10
10	11.93	0.00
15	13.40	0.00
20	14.38	0.23
30	15.37	1.07
40	15.30	2.06
50	14.28	2.87
60	12.60	3.23
70	10.30	3.13
80	7.70	2.47
90	4.87	1.33
95	3.27	0.56
100	0.90	0.90

Rad. L.E. 3.57
" T.E. 0.93

Name of section: N.A.C.A. 98
Size of model: 30" x 5"
Wind velocity: 70.4 ft./sec.
Where tested: L.M.A.L. Date: 1925

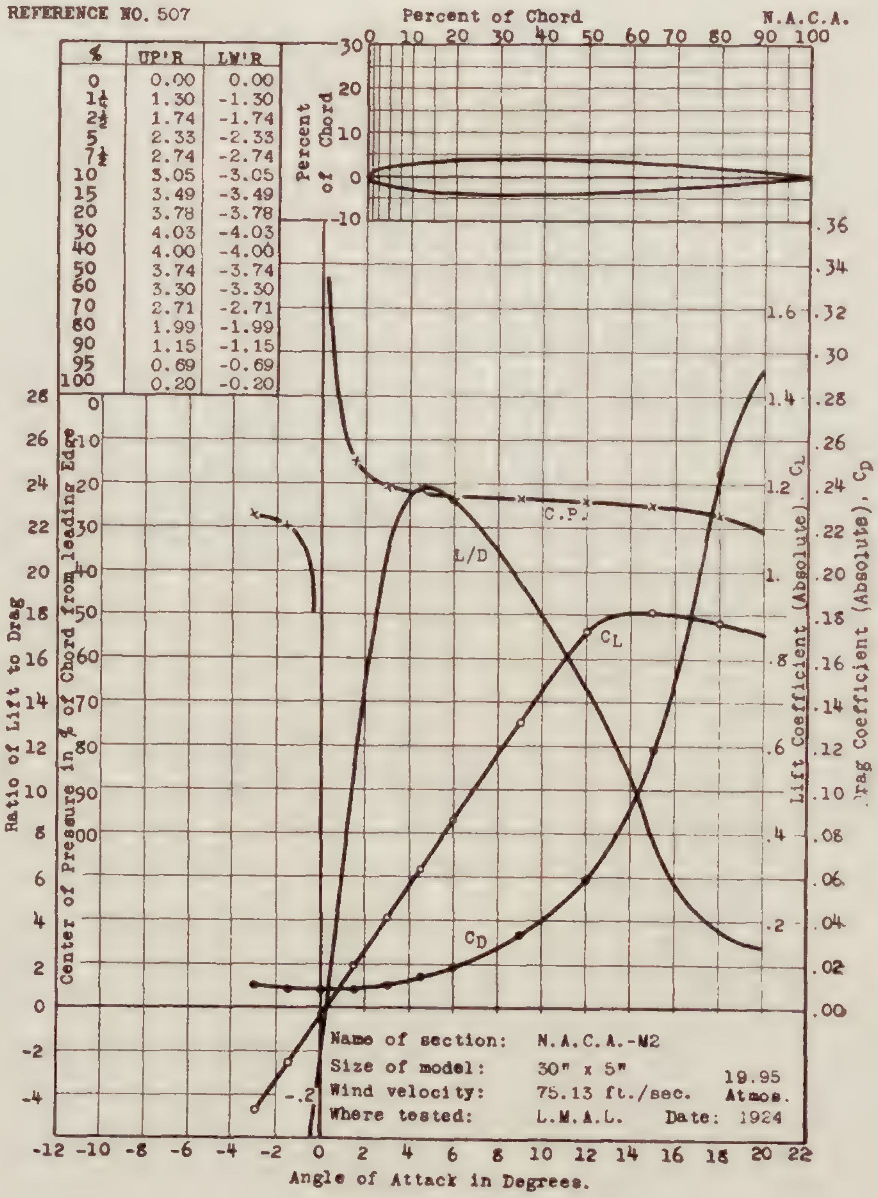
REFERENCE NO. 506



%	UP'R	LW'R
0	0.00	0.00
1¼	1.03	-1.03
2½	1.36	-1.36
5	1.80	-1.80
7½	2.10	-2.10
10	2.34	-2.34
15	2.67	-2.67
20	2.88	-2.88
30	3.08	-3.08
40	3.05	-3.05
50	2.85	-2.85
60	2.53	-2.53
70	2.08	-2.08
80	1.54	-1.54
90	0.91	-0.91
95	0.57	-0.57
100	0.20	-0.20

Name of section: N.A.C.A.-M1
Size of model: 30" x 5"
Wind velocity: 75.46 ft./sec. 20 Atmos.
Where tested: L.M.A.L. Date: 1924

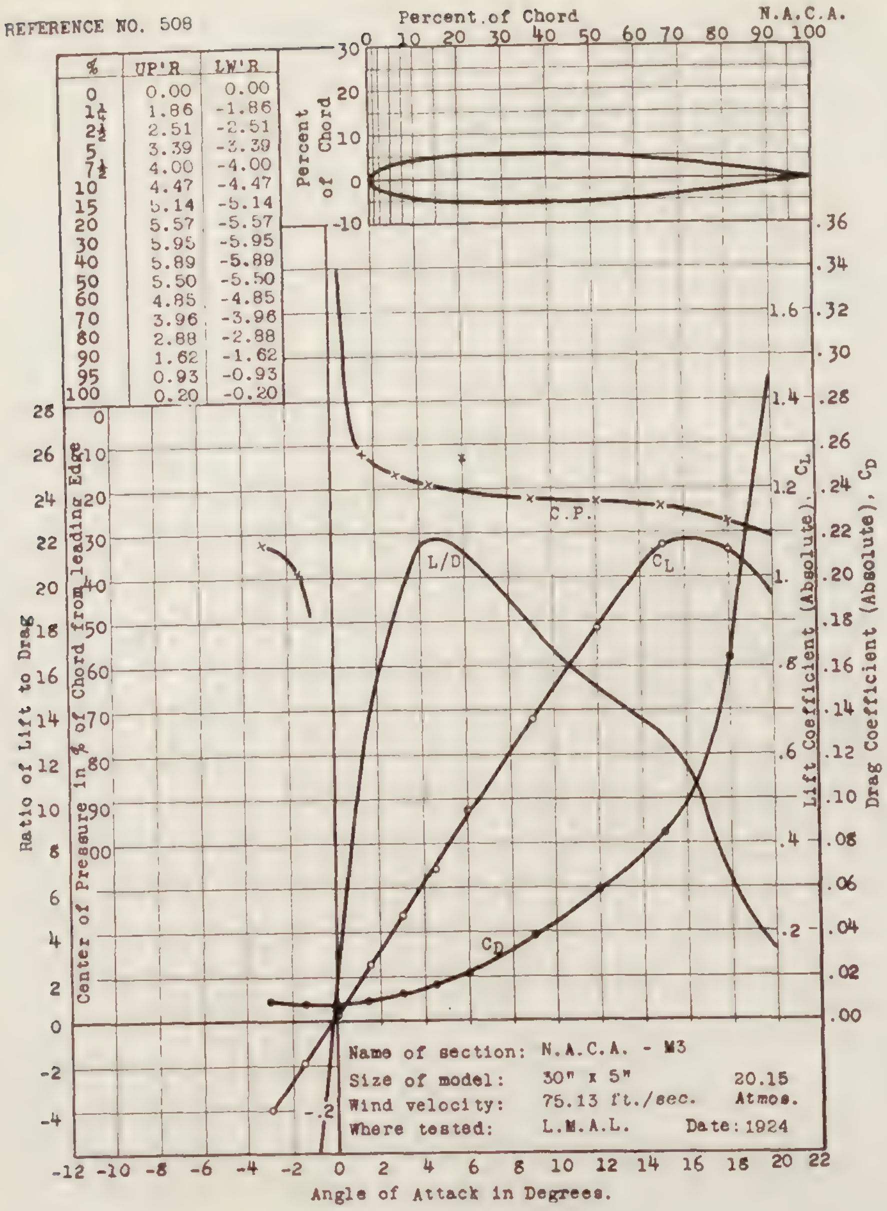
REFERENCE NO. 507



%	UP'R	LW'R
0	0.00	0.00
1¼	1.30	-1.30
2½	1.74	-1.74
5	2.33	-2.33
7½	2.74	-2.74
10	3.05	-3.05
15	3.49	-3.49
20	3.78	-3.78
30	4.03	-4.03
40	4.00	-4.00
50	3.74	-3.74
60	3.30	-3.30
70	2.71	-2.71
80	1.99	-1.99
90	1.15	-1.15
95	0.69	-0.69
100	0.20	-0.20

Name of section: N.A.C.A.-M2
Size of model: 30" x 5"
Wind velocity: 75.13 ft./sec. 19.95 Atmos.
Where tested: L.M.A.L. Date: 1924

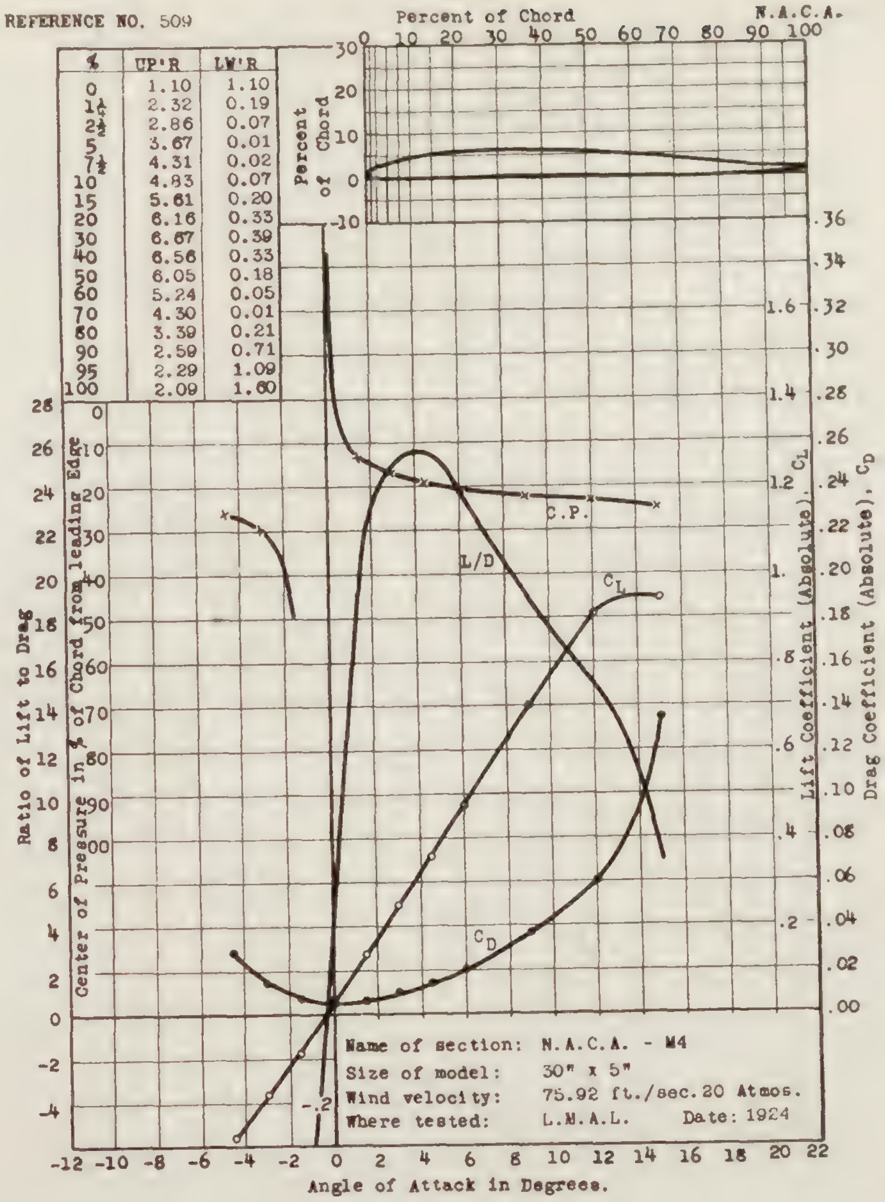
REFERENCE NO. 508



%	UP'R	LW'R
0	0.00	0.00
1¼	1.86	-1.86
2½	2.51	-2.51
5	3.39	-3.39
7½	4.00	-4.00
10	4.47	-4.47
15	5.14	-5.14
20	5.57	-5.57
30	5.95	-5.95
40	5.89	-5.89
50	5.50	-5.50
60	4.85	-4.85
70	3.96	-3.96
80	2.88	-2.88
90	1.62	-1.62
95	0.93	-0.93
100	0.20	-0.20

Name of section: N.A.C.A. - M3
Size of model: 30" x 5" 20.15
Wind velocity: 75.13 ft./sec. Atmos.
Where tested: L.M.A.L. Date: 1924

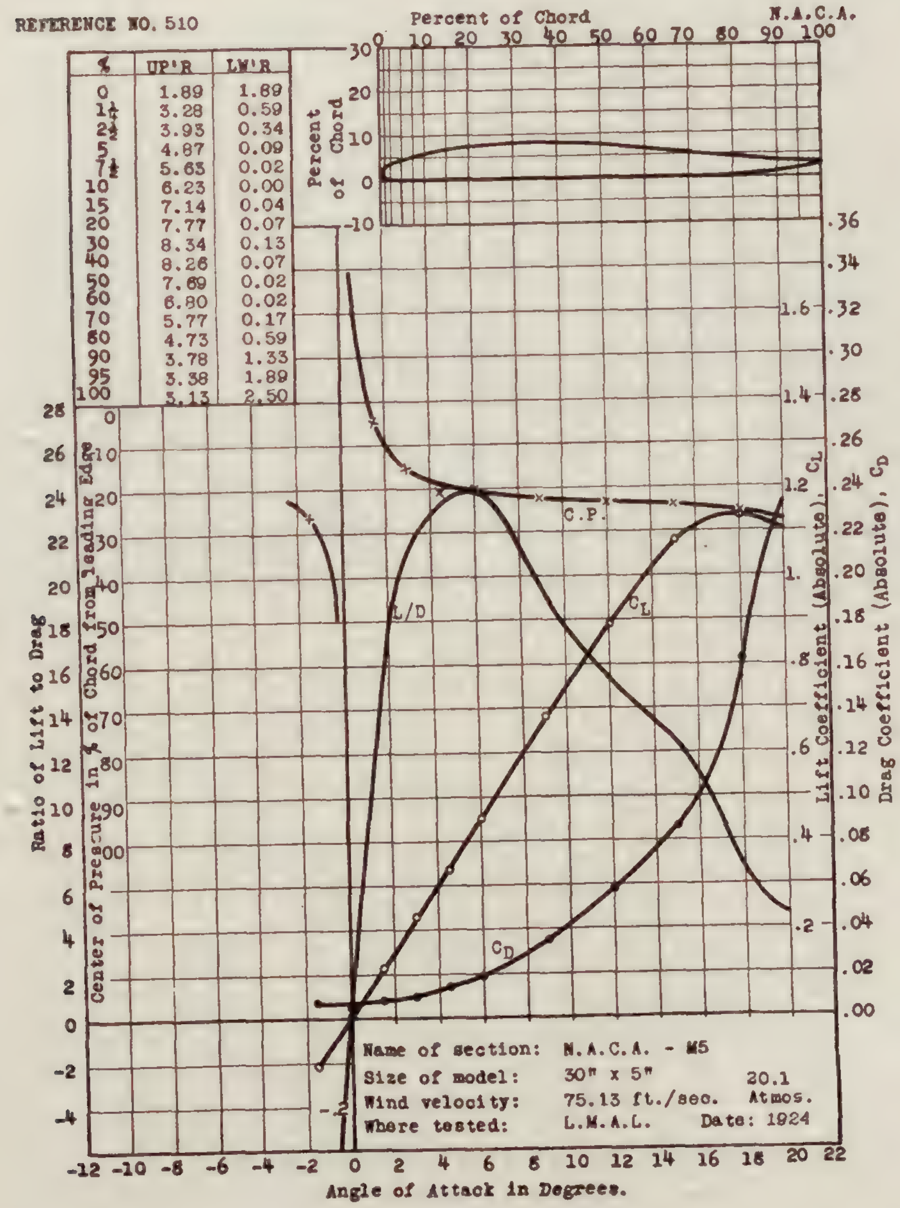
REFERENCE NO. 509



%	UP'R	LW'R
0	1.10	1.10
1¼	2.32	0.19
2½	2.86	0.07
5	3.67	0.01
7½	4.31	0.02
10	4.83	0.07
15	5.61	0.20
20	6.16	0.33
30	6.67	0.39
40	6.56	0.33
50	6.05	0.18
60	5.24	0.05
70	4.30	0.01
80	3.39	0.21
90	2.59	0.71
95	2.29	1.09
100	2.09	1.60

Name of section: N.A.C.A. - M4
Size of model: 30" x 5"
Wind velocity: 75.92 ft./sec. 20 Atmos.
Where tested: L.M.A.L. Date: 1924

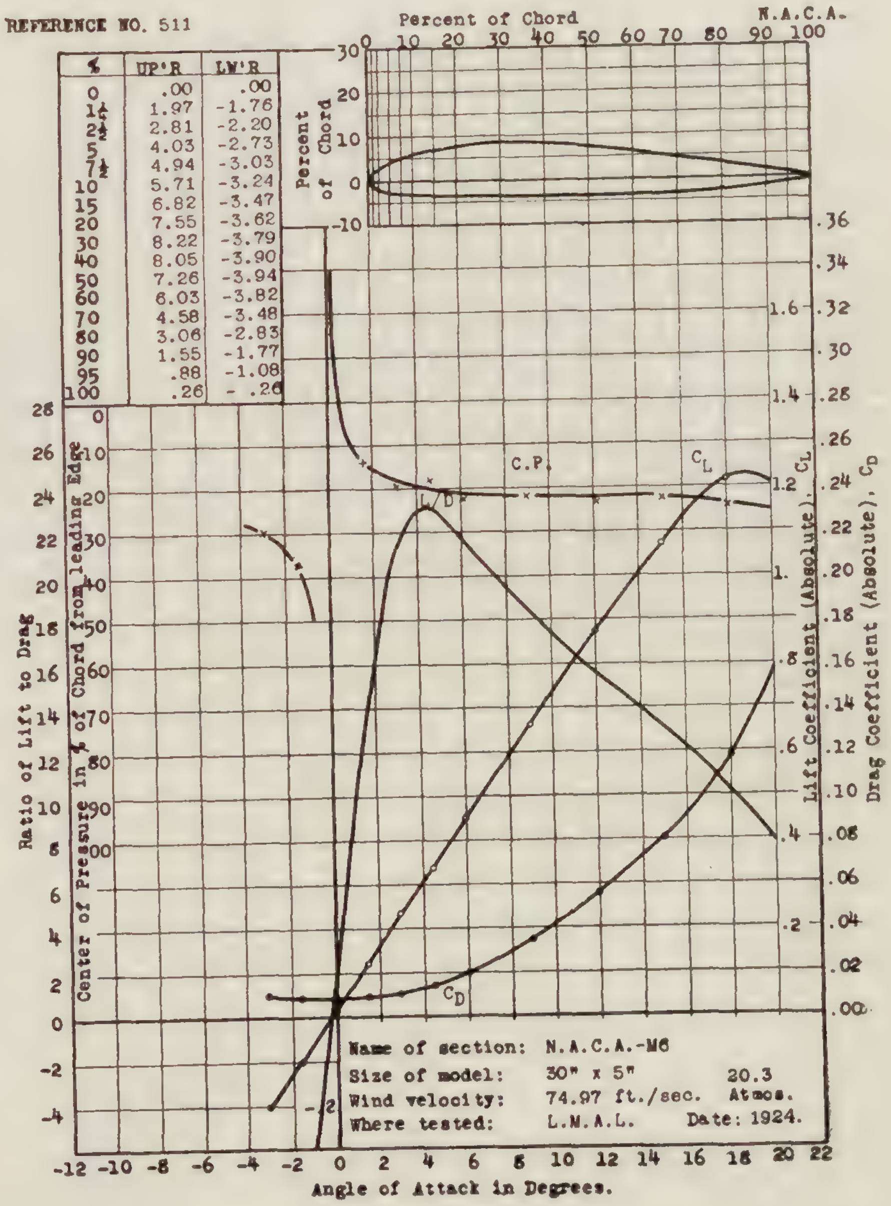
REFERENCE NO. 510



%	UP'R	LW'R
0	1.89	1.89
1¼	3.28	0.59
2½	3.93	0.34
5	4.87	0.09
7½	5.63	0.02
10	6.23	0.00
15	7.14	0.04
20	7.77	0.07
30	8.34	0.13
40	8.26	0.07
50	7.69	0.02
60	6.80	0.02
70	5.77	0.17
80	4.73	0.59
90	3.78	1.33
95	3.38	1.89
100	3.13	2.50

Name of section: N.A.C.A. - M5
Size of model: 30" x 5" 20.1
Wind velocity: 75.13 ft./sec. Atmos.
Where tested: L.M.A.L. Date: 1924

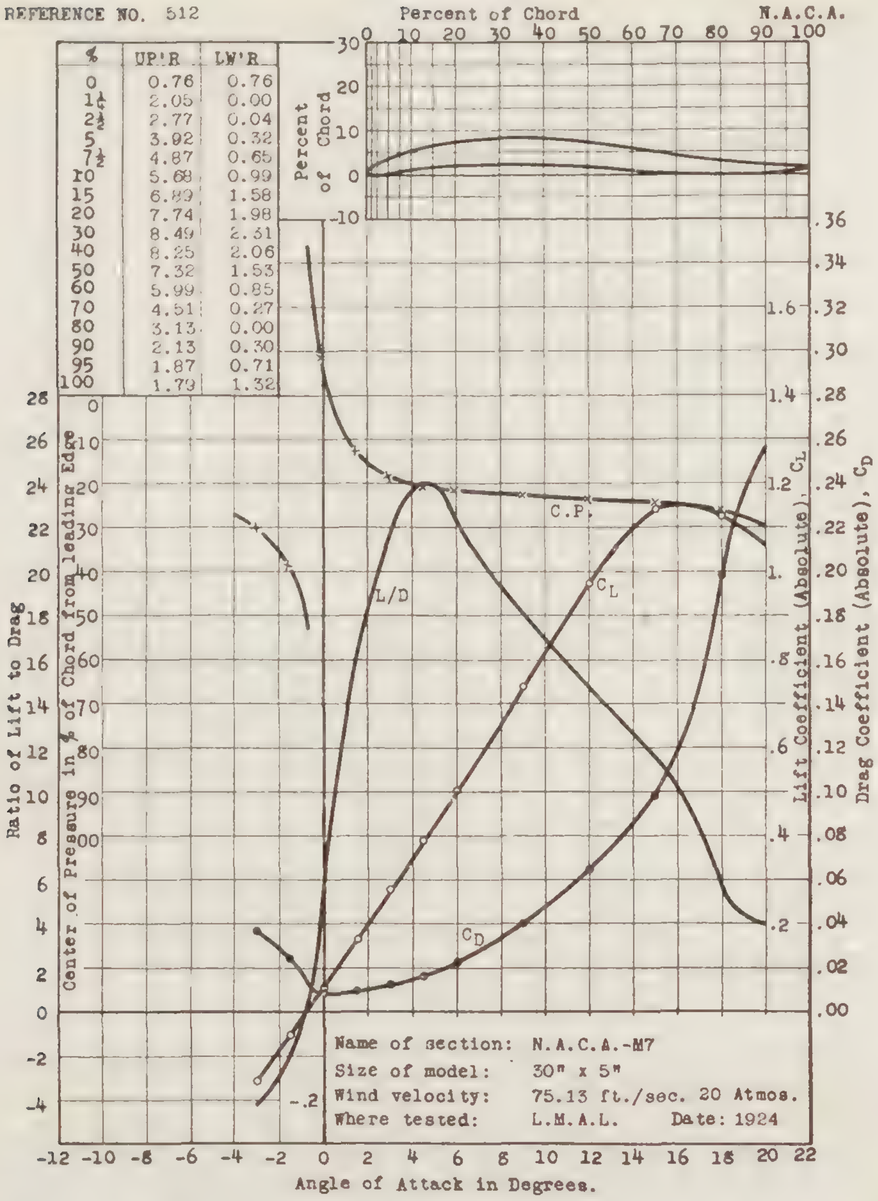
REFERENCE NO. 511



%	UP'R	LW'R
0	.00	.00
1¼	1.97	-1.76
2½	2.81	-2.20
5	4.03	-2.73
7½	4.94	-3.03
10	5.71	-3.24
15	6.82	-3.47
20	7.55	-3.62
30	8.22	-3.79
40	8.05	-3.90
50	7.26	-3.94
60	6.03	-3.82
70	4.58	-3.48
80	3.06	-2.83
90	1.55	-1.77
95	.88	-1.08
100	.26	- .26

Name of section: N.A.C.A.-M6
Size of model: 30" x 5" 20.3
Wind velocity: 74.97 ft./sec. Atmos.
Where tested: L.M.A.L. Date: 1924.

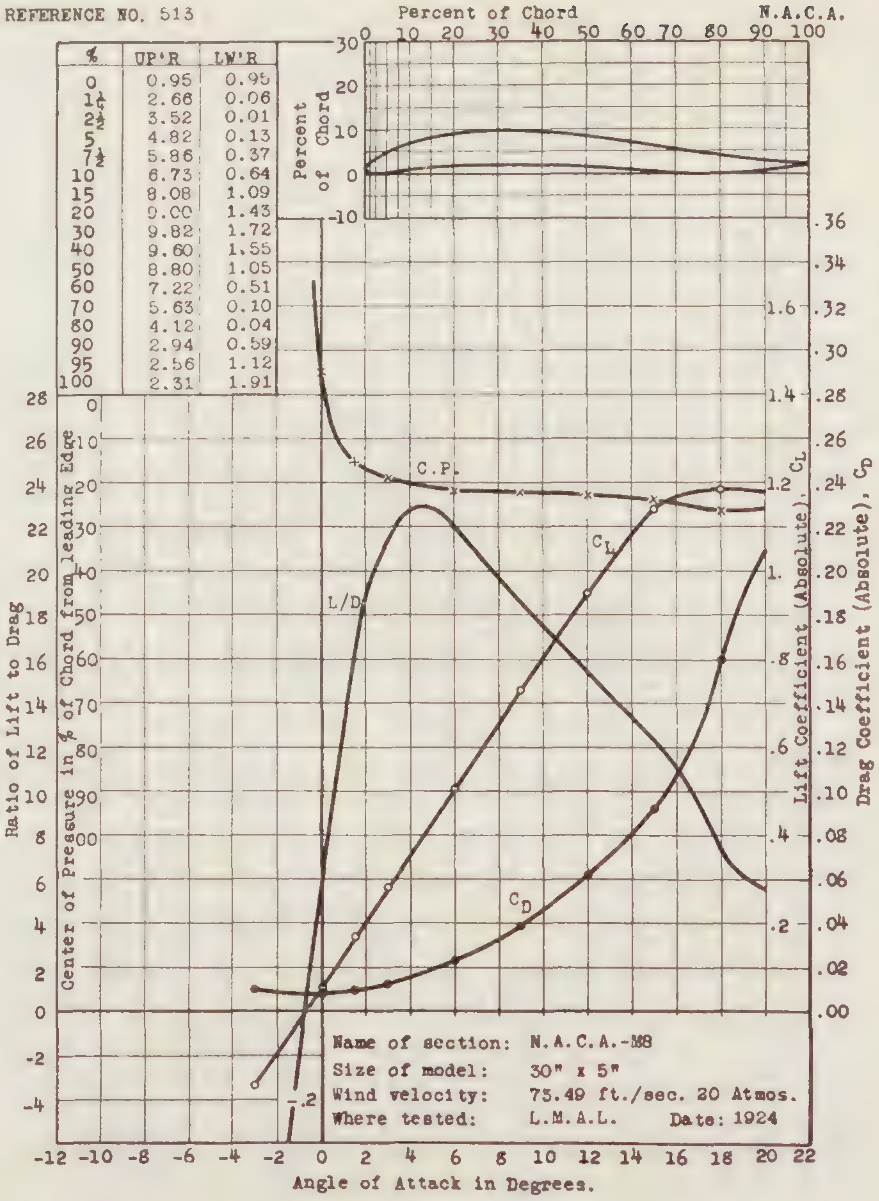
REFERENCE NO. 512



%	UP'R	LW'R
0	0.76	0.76
1¼	2.05	0.00
2½	2.77	0.04
5	3.92	0.32
7½	4.87	0.65
10	5.68	0.99
15	6.89	1.58
20	7.74	1.98
30	8.49	2.31
40	8.25	2.06
50	7.32	1.53
60	5.99	0.85
70	4.51	0.27
80	3.13	0.00
90	2.13	0.30
95	1.87	0.71
100	1.79	1.32

Name of section: N.A.C.A.-M7
Size of model: 30" x 5"
Wind velocity: 75.13 ft./sec. 20 Atmos.
Where tested: L.M.A.L. Date: 1924

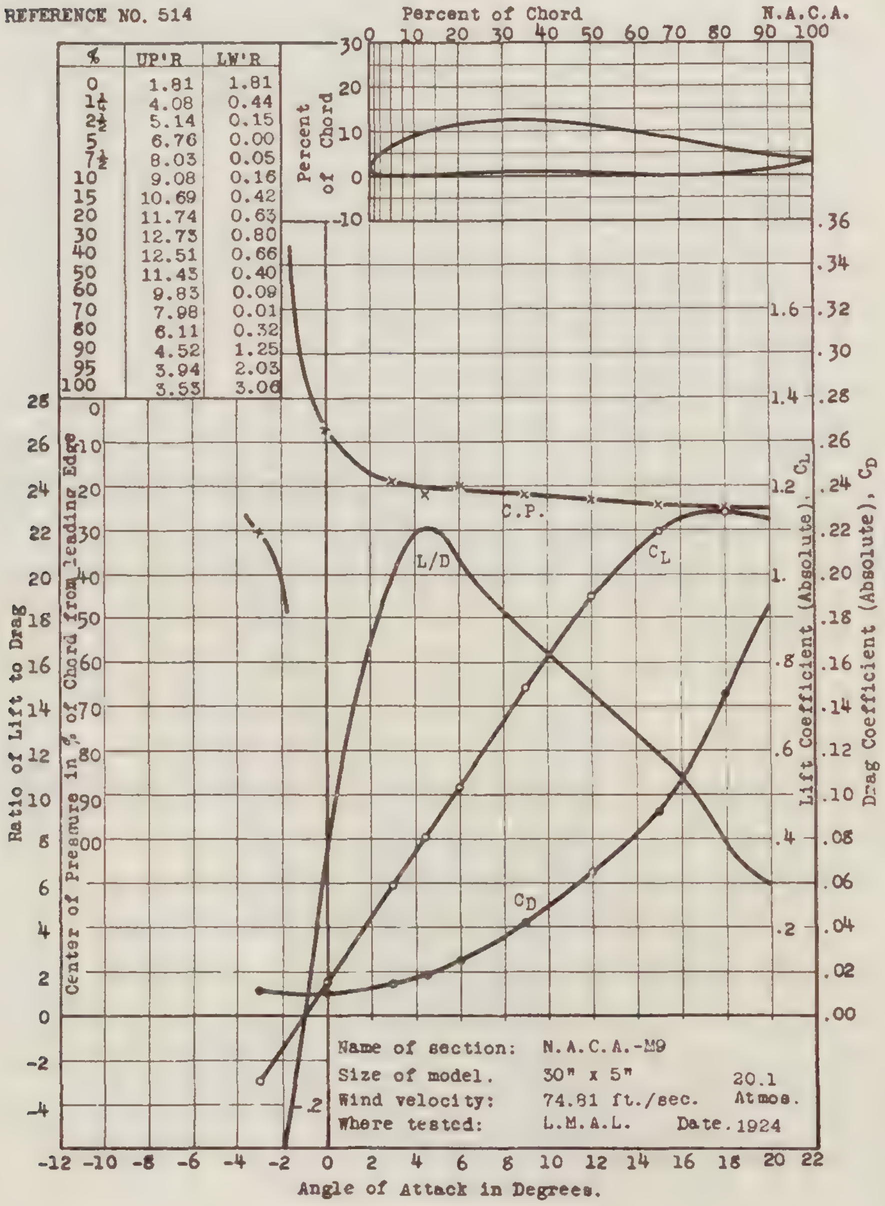
REFERENCE NO. 513



%	UP'R	LW'R
0	0.95	0.95
1¼	2.66	0.06
2½	3.52	0.01
5	4.82	0.13
7½	5.86	0.37
10	6.73	0.64
15	8.08	1.09
20	9.00	1.43
30	9.82	1.72
40	9.60	1.55
50	8.80	1.05
60	7.22	0.51
70	5.63	0.10
80	4.12	0.04
90	2.94	0.59
95	2.56	1.12
100	2.31	1.91

Name of section: N.A.C.A.-M8
Size of model: 30" x 5"
Wind velocity: 75.49 ft./sec. 20 Atmos.
Where tested: L.M.A.L. Date: 1924

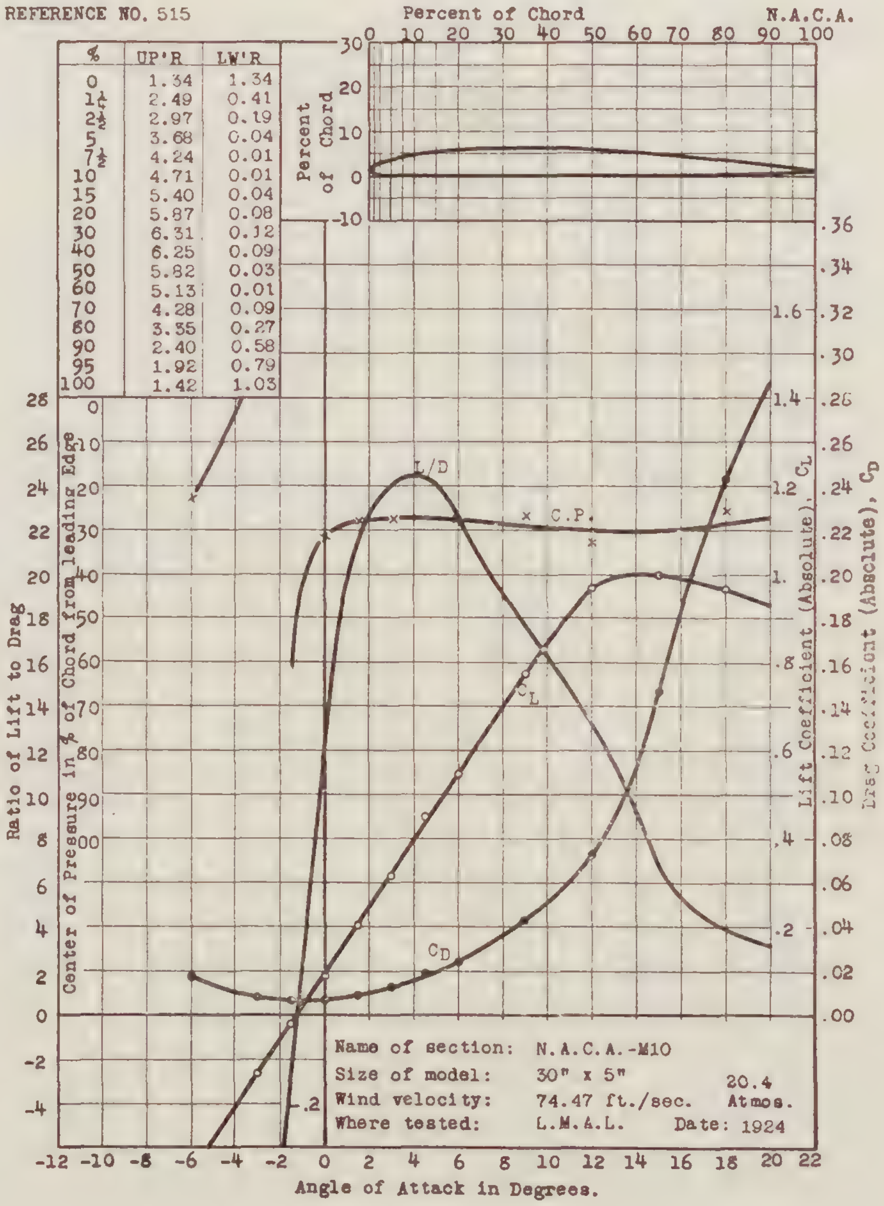
REFERENCE NO. 514



%	UP'R	LW'R
0	1.81	1.81
1¼	4.08	0.44
2½	5.14	0.15
5	6.76	0.00
7½	8.03	0.05
10	9.08	0.16
15	10.69	0.42
20	11.74	0.63
30	12.73	0.80
40	12.51	0.66
50	11.43	0.40
60	9.83	0.08
70	7.98	0.01
80	6.11	0.32
90	4.52	1.25
95	3.94	2.03
100	3.53	3.06

Name of section: N.A.C.A.-M9
Size of model. 30" x 5"
Wind velocity: 74.81 ft./sec. 20.1 Atmos.
Where tested: L.M.A.L. Date. 1924

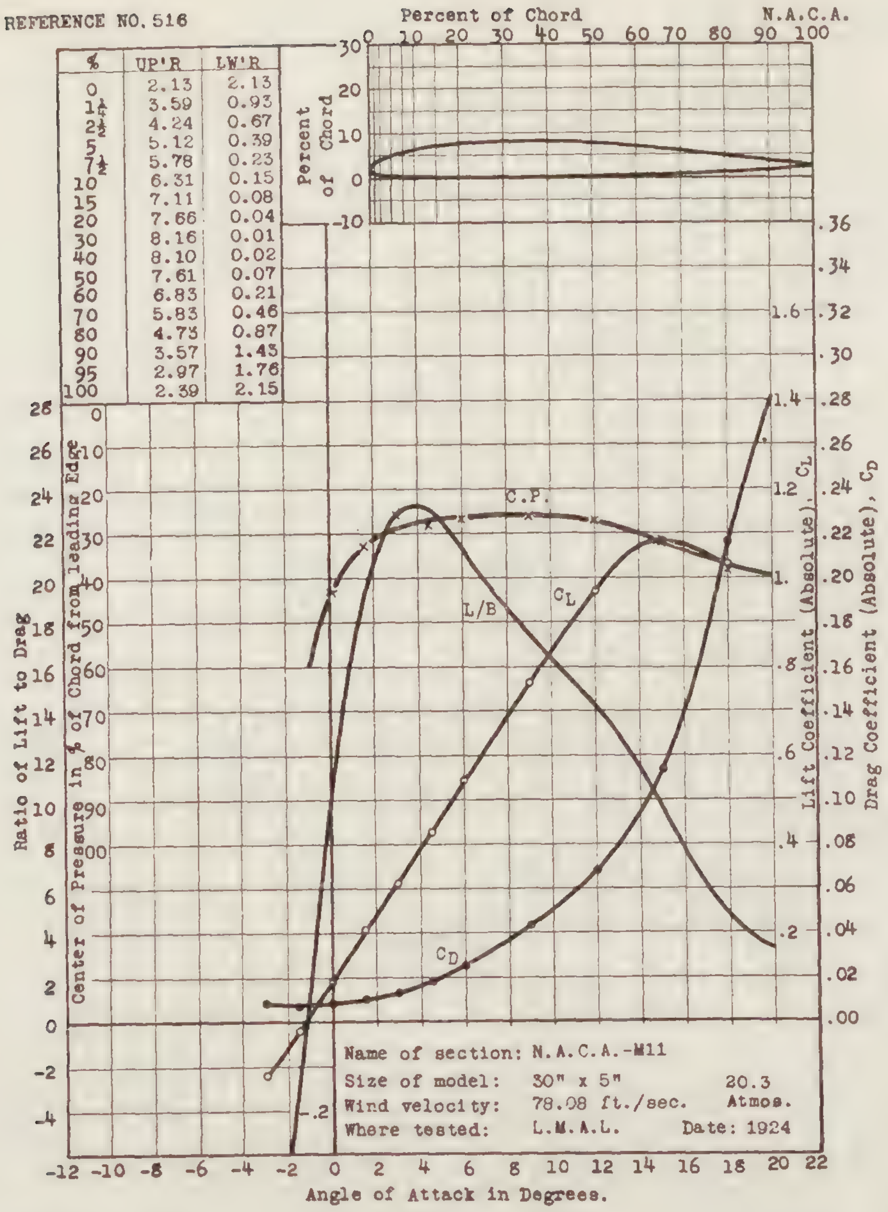
REFERENCE NO. 515



%	UP'R	LW'R
0	1.34	1.34
1¼	2.49	0.41
2½	2.97	0.19
5	3.68	0.04
7½	4.24	0.01
10	4.71	0.01
15	5.40	0.04
20	5.87	0.08
30	6.31	0.12
40	6.25	0.09
50	5.82	0.03
60	5.13	0.01
70	4.28	0.09
80	3.35	0.27
90	2.40	0.58
95	1.92	0.79
100	1.42	1.03

Name of section: N.A.C.A.-M10
Size of model: 30" x 5"
Wind velocity: 74.47 ft./sec. 20.4 Atmos.
Where tested: L.M.A.L. Date: 1924

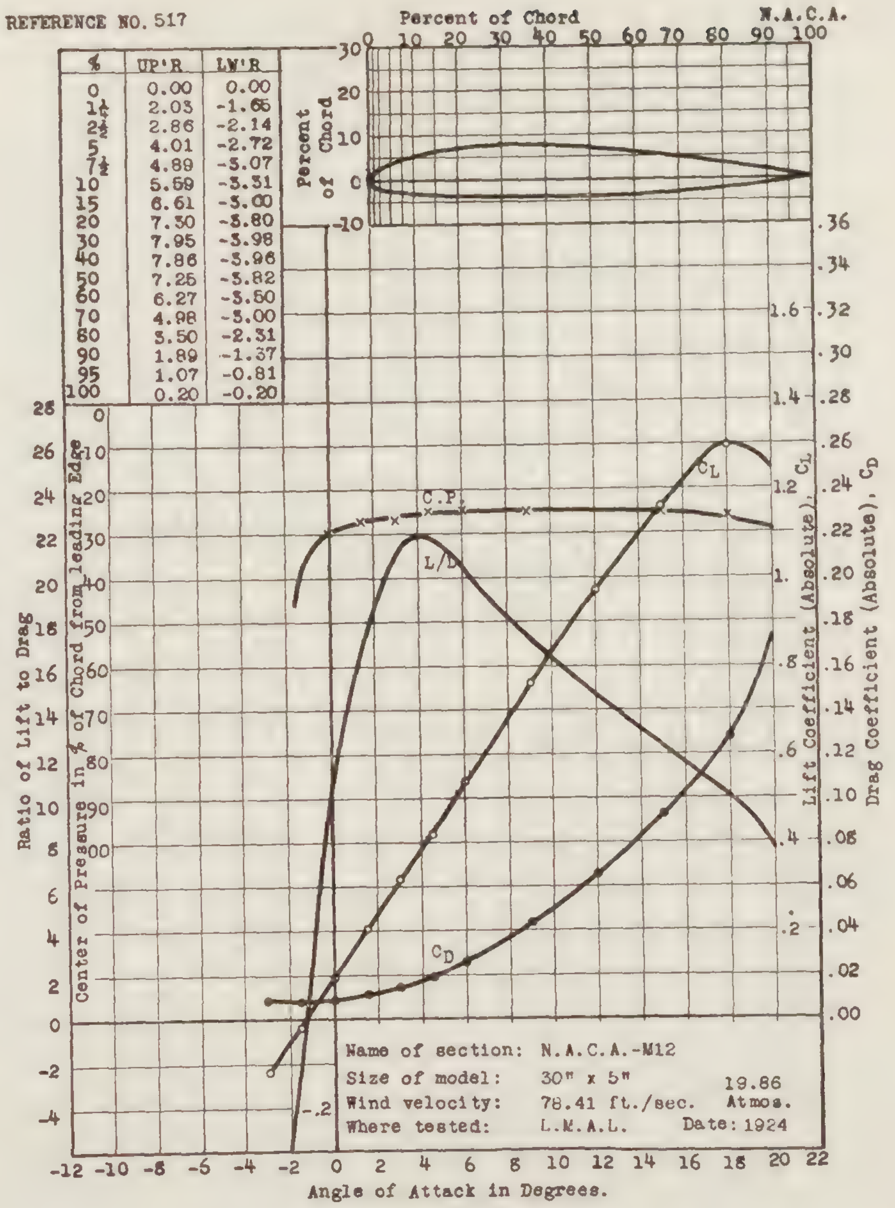
REFERENCE NO. 516



%	UP'R	LW'R
0	2.13	2.13
1¼	3.59	0.93
2½	4.24	0.67
5	5.12	0.39
7½	5.78	0.23
10	6.31	0.15
15	7.11	0.08
20	7.66	0.04
30	8.16	0.01
40	8.10	0.02
50	7.61	0.07
60	6.83	0.21
70	5.83	0.46
80	4.73	0.87
90	3.57	1.43
95	2.97	1.76
100	2.39	2.15

Name of section: N.A.C.A.-M11
Size of model: 30" x 5" 20.3
Wind velocity: 78.08 ft./sec. Atmos.
Where tested: L.M.A.L. Date: 1924

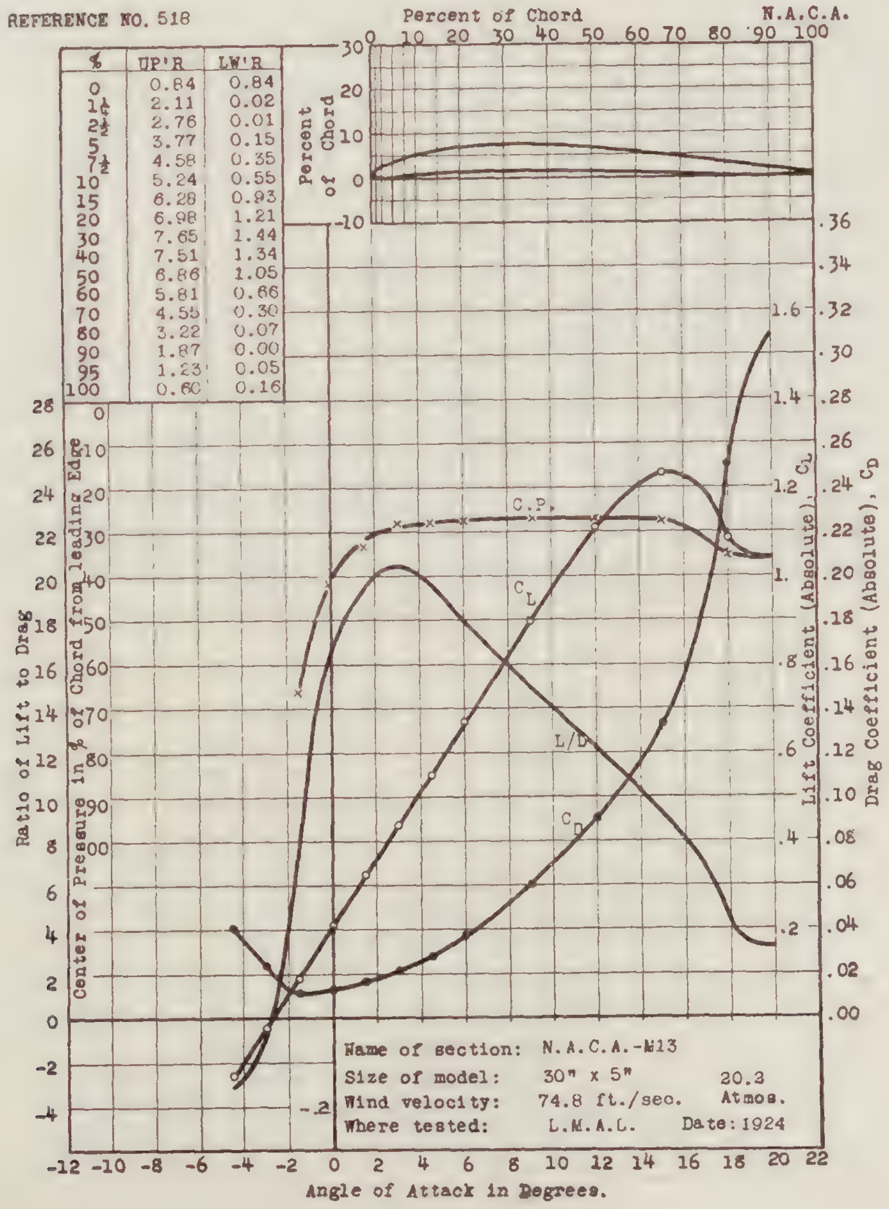
REFERENCE NO. 517



%	UP'R	LW'R
0	0.00	0.00
1¼	2.03	-1.65
2½	2.86	-2.14
5	4.01	-2.72
7½	4.89	-3.07
10	5.59	-3.31
15	6.61	-3.00
20	7.30	-3.80
30	7.95	-3.98
40	7.86	-3.96
50	7.25	-3.82
60	6.27	-3.50
70	4.98	-3.00
80	3.50	-2.31
90	1.89	-1.37
95	1.07	-0.81
100	0.20	-0.20

Name of section: N.A.C.A.-M12
Size of model: 30" x 5" 19.86
Wind velocity: 78.41 ft./sec. Atmos.
Where tested: L.M.A.L. Date: 1924

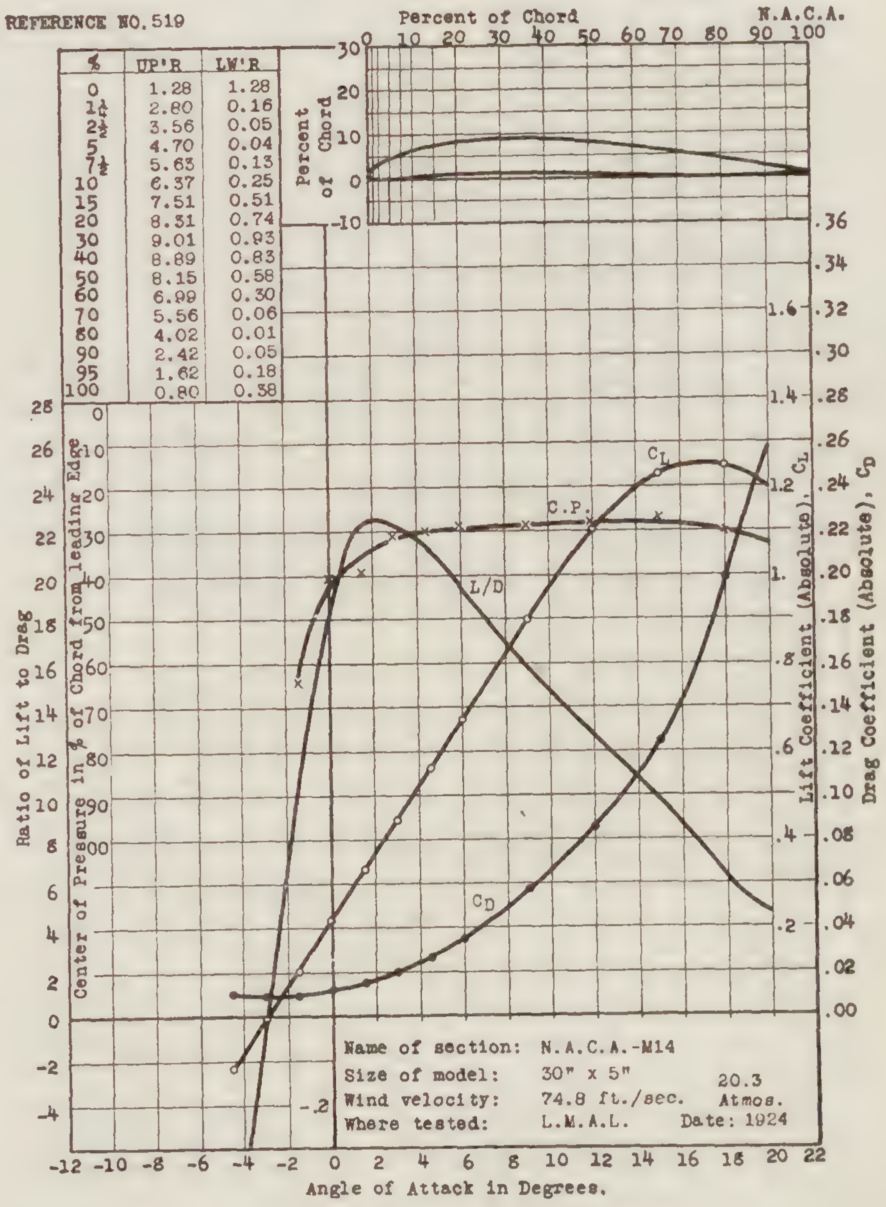
REFERENCE NO. 518



%	UP'R	LW'R
0	0.84	0.84
1¼	2.11	0.02
2½	2.76	0.01
5	3.77	0.15
7½	4.58	0.35
10	5.24	0.55
15	6.28	0.93
20	6.98	1.21
30	7.65	1.44
40	7.51	1.34
50	6.86	1.05
60	5.81	0.66
70	4.55	0.30
80	3.22	0.07
90	1.87	0.00
95	1.23	0.05
100	0.60	0.16

Name of section: N.A.C.A.-M13
Size of model: 30" x 5" 20.3
Wind velocity: 74.8 ft./sec. Atmos.
Where tested: L.M.A.L. Date: 1924

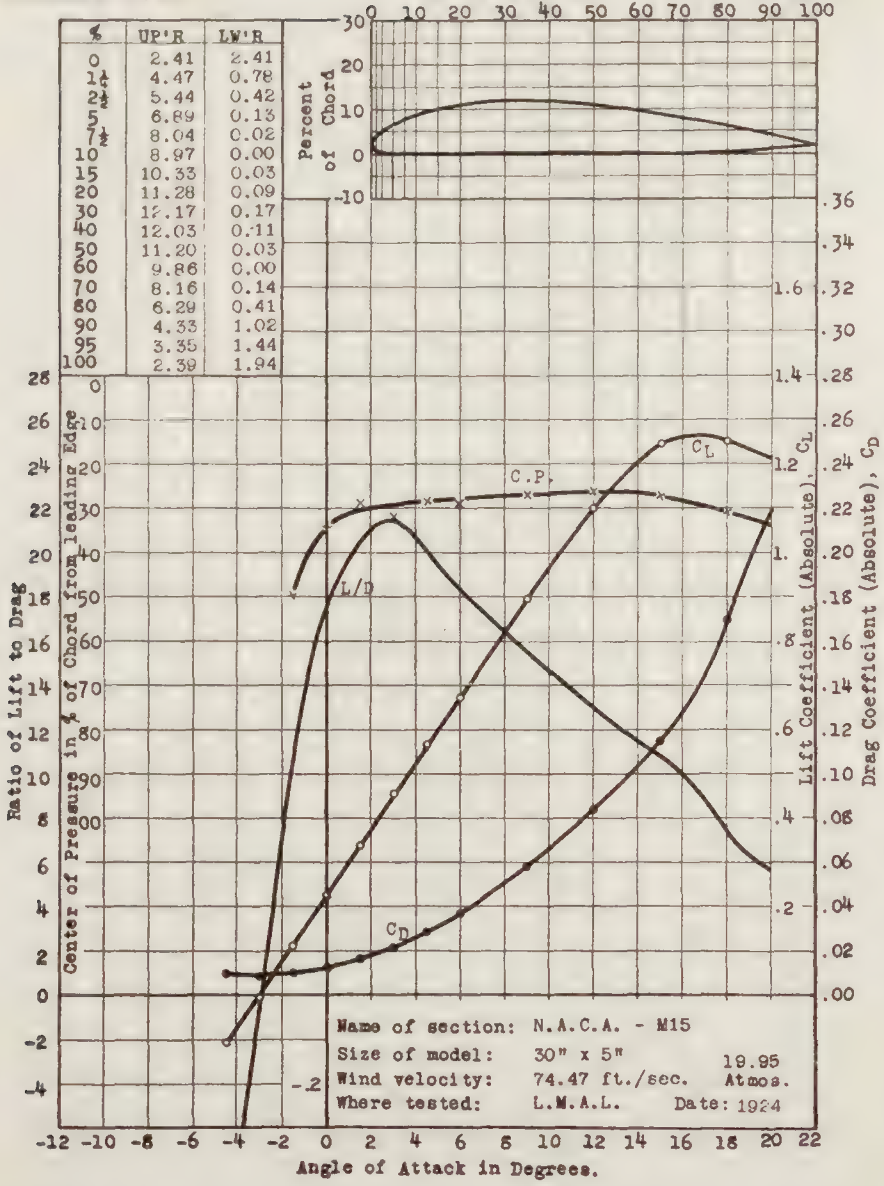
REFERENCE NO. 519



%	UP'R	LW'R
0	1.28	1.28
1¼	2.80	0.16
2½	3.56	0.05
5	4.70	0.04
7½	5.63	0.13
10	6.37	0.25
15	7.51	0.51
20	8.31	0.74
30	9.01	0.93
40	8.89	0.83
50	8.15	0.58
60	6.99	0.30
70	5.56	0.06
80	4.02	0.01
90	2.42	0.05
95	1.62	0.18
100	0.80	0.38

Name of section: N.A.C.A.-M14
Size of model: 30" x 5" 20.3
Wind velocity: 74.8 ft./sec. Atmos.
Where tested: L.M.A.L. Date: 1924

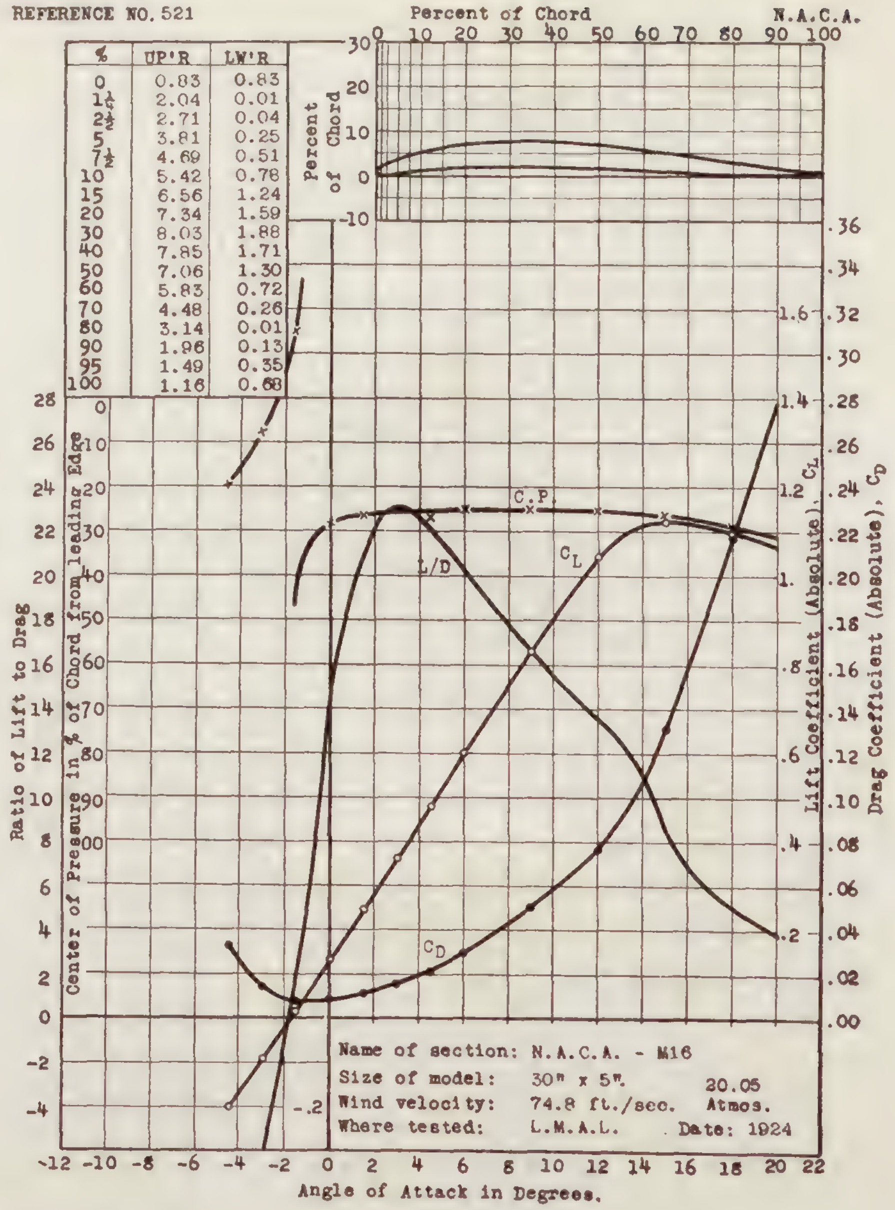
REFERENCE NO. 520



%	UP'R	LW'R
0	2.41	2.41
1¼	4.47	0.78
2½	5.44	0.42
5	6.89	0.13
7½	8.04	0.02
10	8.97	0.00
15	10.33	0.03
20	11.28	0.09
30	12.17	0.17
40	12.03	0.11
50	11.20	0.03
60	9.86	0.00
70	8.16	0.14
80	6.29	0.41
90	4.33	1.02
95	3.35	1.44
100	2.39	1.94

Name of section: N.A.C.A. - M15
Size of model: 30" x 5"
Wind velocity: 74.47 ft./sec.
Where tested: L.M.A.L.
19.95 Atmos.
Date: 1924

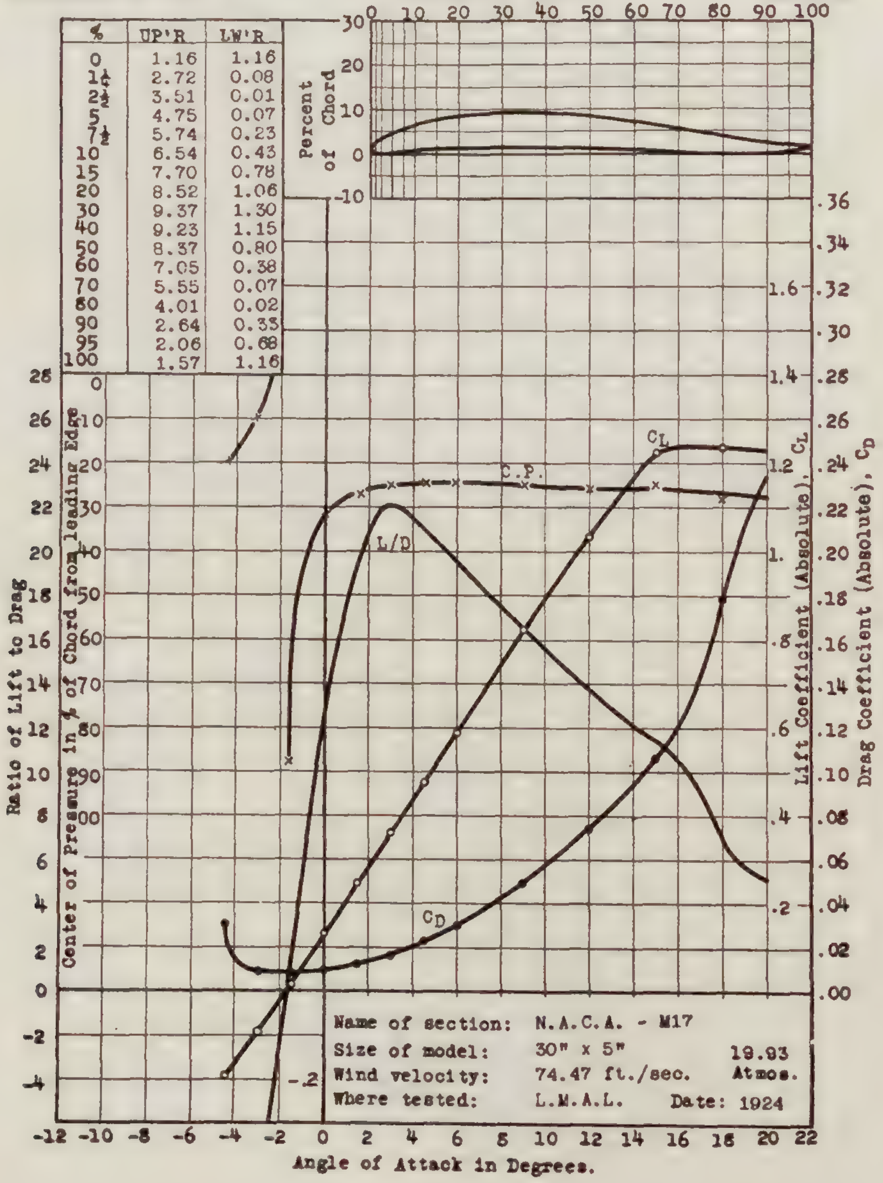
REFERENCE NO. 521



%	UP'R	LW'R
0	0.83	0.83
1¼	2.04	0.01
2½	2.71	0.04
5	3.81	0.25
7½	4.69	0.51
10	5.42	0.78
15	6.56	1.24
20	7.34	1.59
30	8.03	1.88
40	7.85	1.71
50	7.06	1.30
60	5.83	0.72
70	4.48	0.26
80	3.14	0.01
90	1.96	0.13
95	1.49	0.35
100	1.16	0.68

Name of section: N.A.C.A. - M16
Size of model: 30" x 5"
Wind velocity: 74.8 ft./sec.
Where tested: L.M.A.L.
20.05 Atmos.
Date: 1924

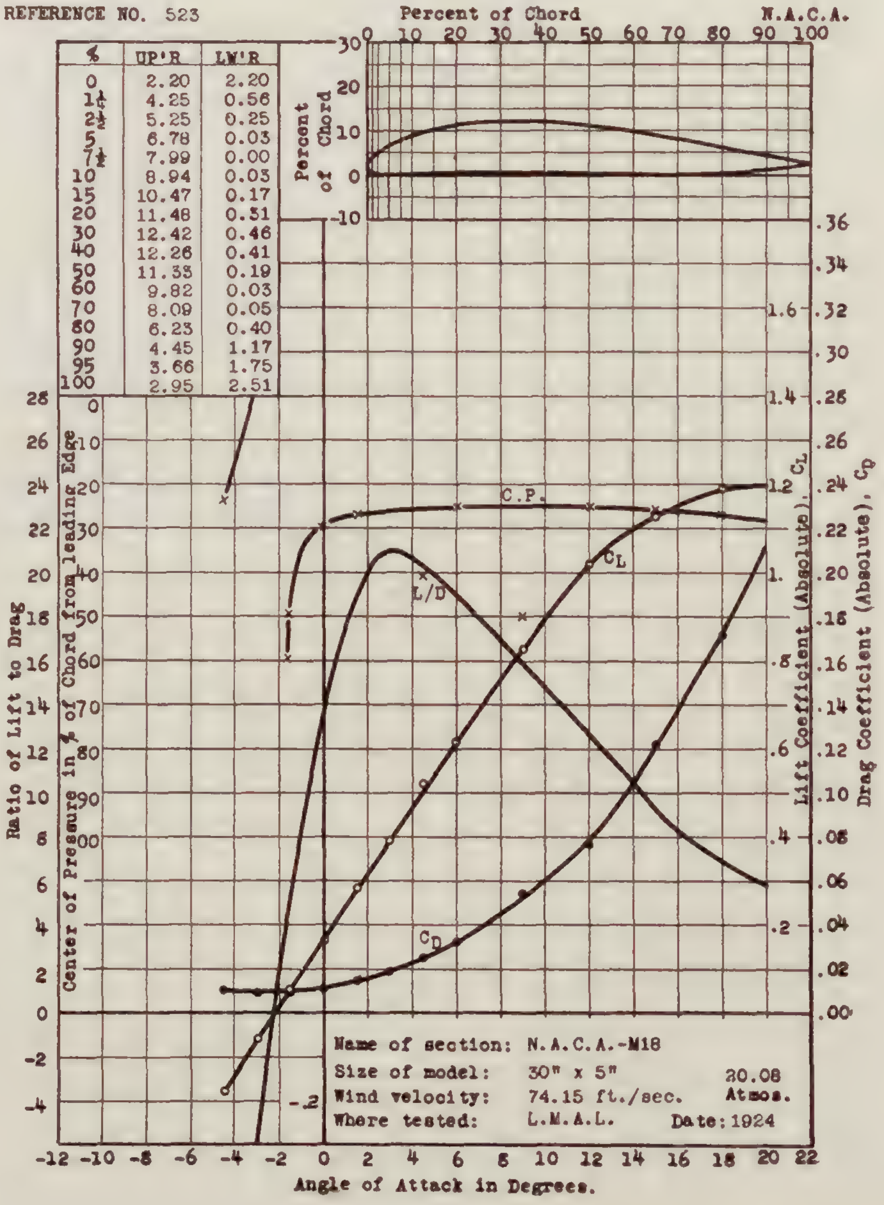
REFERENCE NO. 522



%	UP'R	LW'R
0	1.16	1.16
1¼	2.72	0.08
2½	3.51	0.01
5	4.75	0.07
7½	5.74	0.23
10	6.54	0.43
15	7.70	0.78
20	8.52	1.06
30	9.37	1.30
40	9.23	1.15
50	8.37	0.80
60	7.05	0.38
70	5.55	0.07
80	4.01	0.02
90	2.64	0.33
95	2.06	0.68
100	1.57	1.16

Name of section: N.A.C.A. - M17
Size of model: 30" x 5"
Wind velocity: 74.47 ft./sec.
Where tested: L.M.A.L.
19.93 Atmos.
Date: 1924

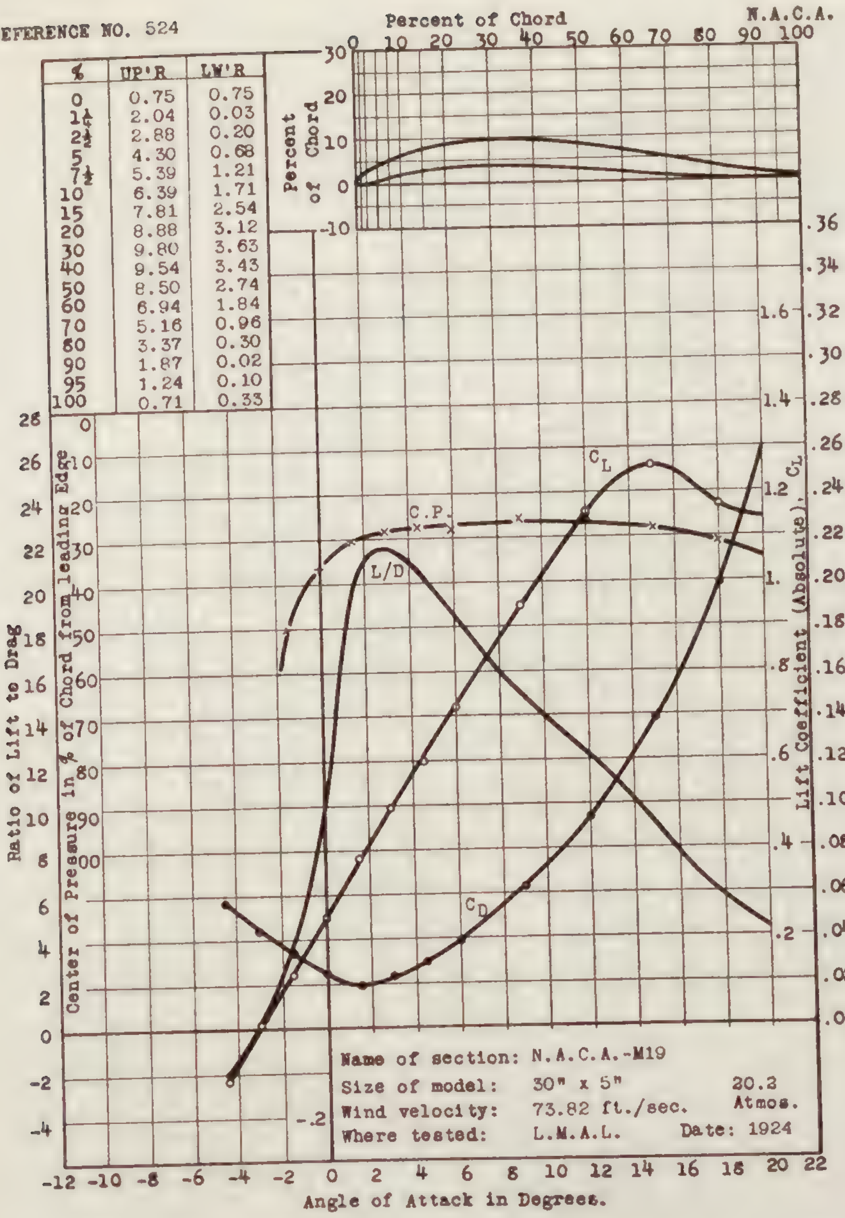
REFERENCE NO. 523



%	UP'R	LW'R
0	2.20	2.20
1¼	4.25	0.56
2½	5.25	0.25
5	6.78	0.03
7½	7.99	0.00
10	8.94	0.03
15	10.47	0.17
20	11.48	0.31
30	12.42	0.46
40	12.26	0.41
50	11.33	0.19
60	9.82	0.03
70	8.09	0.05
80	6.23	0.40
90	4.45	1.17
95	3.66	1.75
100	2.95	2.51

Name of section: N.A.C.A.-M18
Size of model: 30" x 5"
Wind velocity: 74.15 ft./sec.
Where tested: L.M.A.L.
20.08 Atmos.
Date: 1924

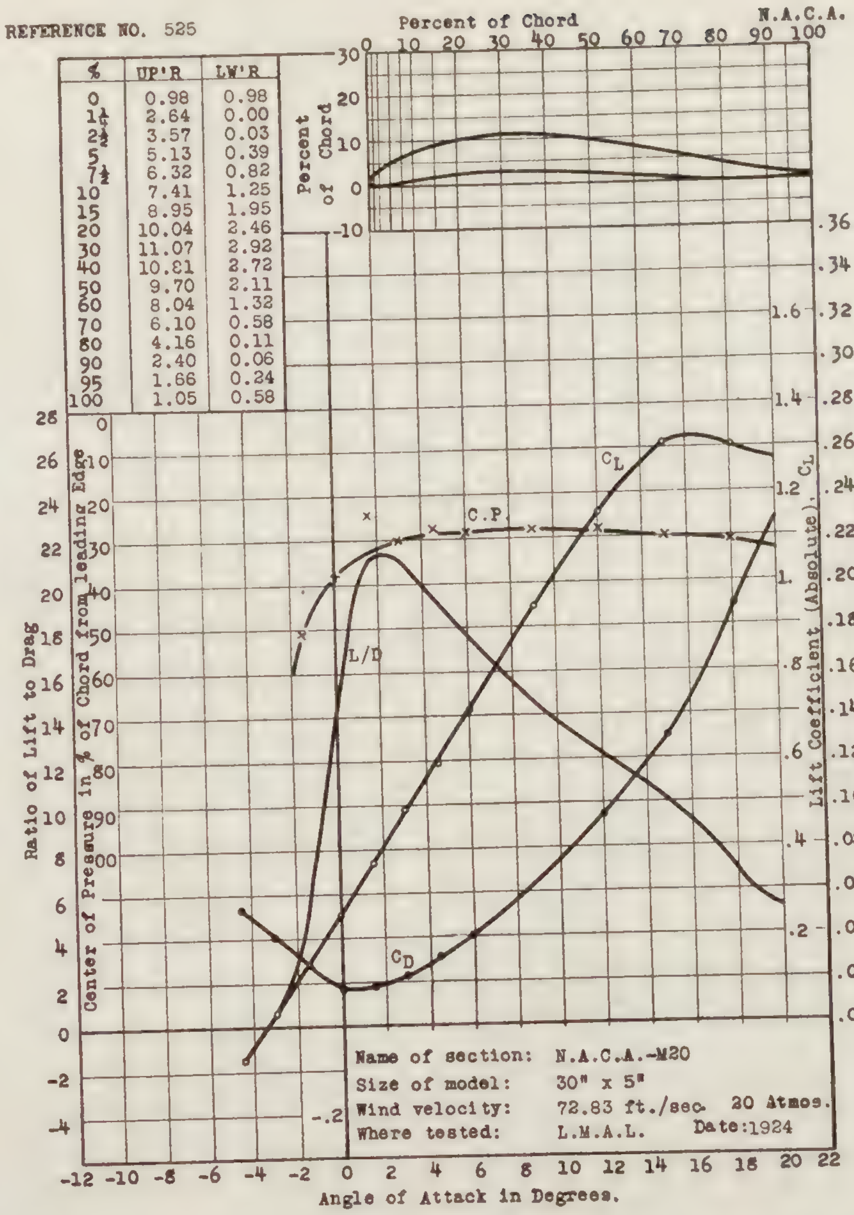
REFERENCE NO. 524



%	UP'R	LW'R
0	0.75	0.75
1¼	2.04	0.03
2½	2.88	0.20
5	4.30	0.68
7½	5.39	1.21
10	6.39	1.71
15	7.81	2.54
20	8.88	3.12
30	9.80	3.63
40	9.54	3.43
50	8.50	2.74
60	6.94	1.84
70	5.16	0.96
80	3.37	0.30
90	1.87	0.02
95	1.24	0.10
100	0.71	0.33

Name of section: N.A.C.A.-M19
Size of model: 30" x 5" 20.3 Atmos.
Wind velocity: 73.82 ft./sec.
Where tested: L.M.A.L. Date: 1924

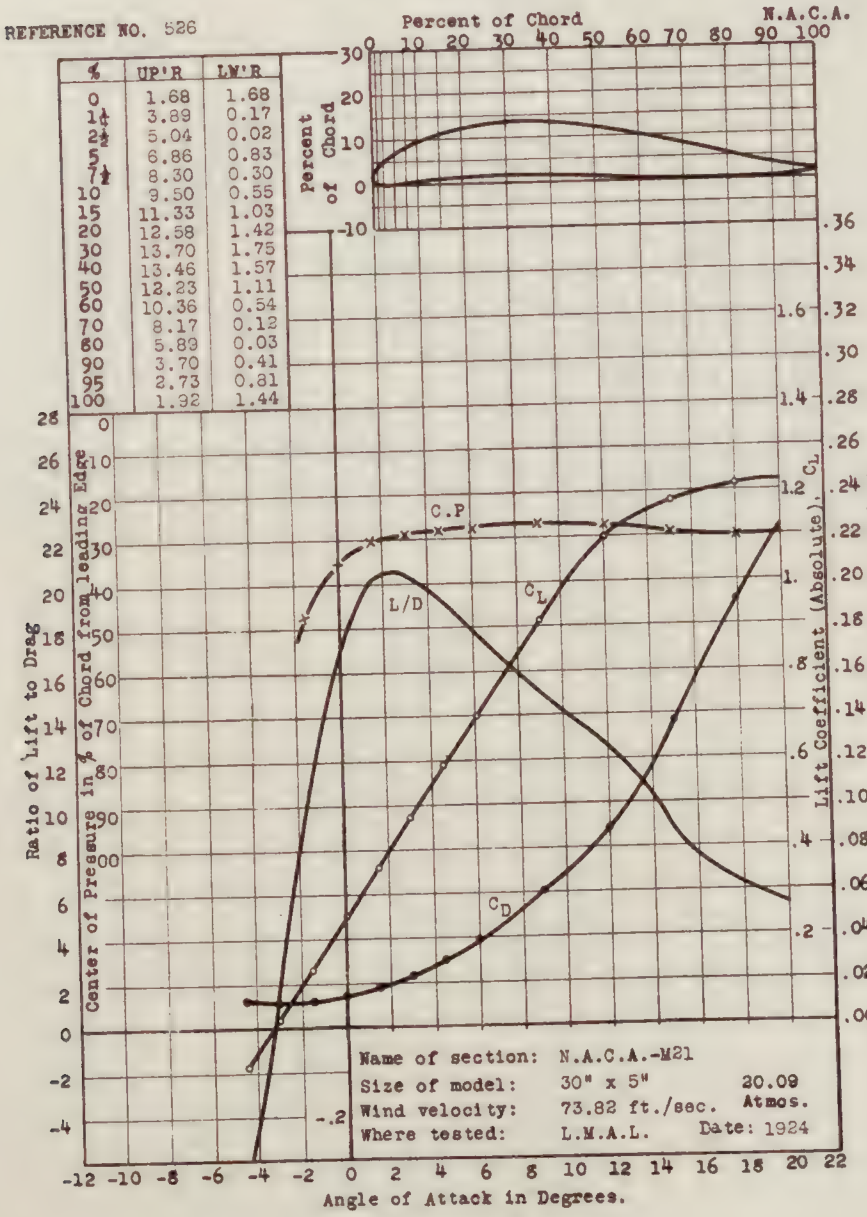
REFERENCE NO. 525



%	UP'R	LW'R
0	0.98	0.98
1¼	2.64	0.00
2½	3.57	0.03
5	5.13	0.39
7½	6.32	0.82
10	7.41	1.25
15	8.95	1.95
20	10.04	2.46
30	11.07	2.92
40	10.81	2.72
50	9.70	2.11
60	8.04	1.32
70	6.10	0.58
80	4.16	0.11
90	2.40	0.06
95	1.66	0.24
100	1.05	0.58

Name of section: N.A.C.A.-M20
Size of model: 30" x 5"
Wind velocity: 72.83 ft./sec. 20 Atmos.
Where tested: L.M.A.L. Date: 1924

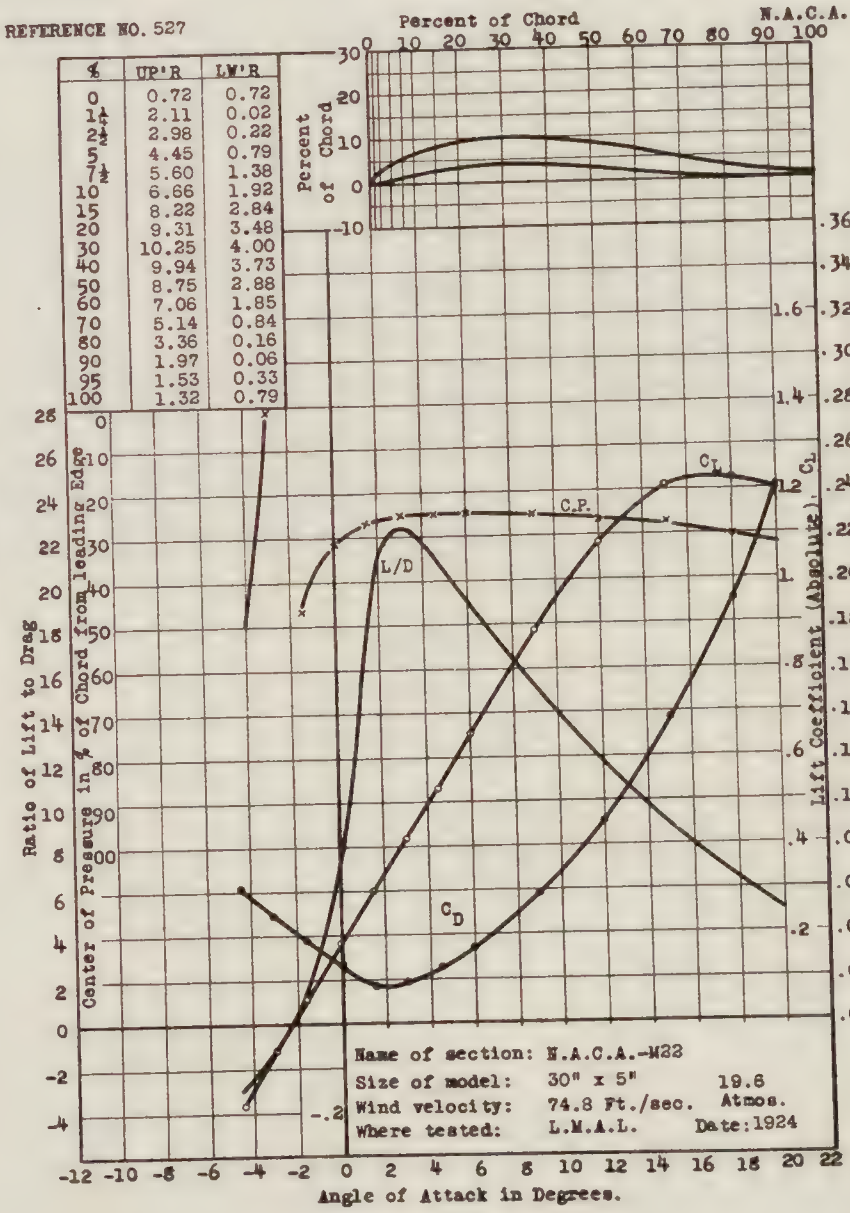
REFERENCE NO. 526



%	UP'R	LW'R
0	1.68	1.68
1¼	3.89	0.17
2½	5.04	0.02
5	6.86	0.83
7½	8.30	0.30
10	9.50	0.55
15	11.33	1.03
20	12.58	1.42
30	13.70	1.75
40	13.46	1.57
50	12.23	1.11
60	10.36	0.54
70	8.17	0.12
80	5.89	0.03
90	3.70	0.41
95	2.73	0.81
100	1.92	1.44

Name of section: N.A.C.A.-M21
Size of model: 30" x 5" 20.09 Atmos.
Wind velocity: 73.82 ft./sec.
Where tested: L.M.A.L. Date: 1924

REFERENCE NO. 527

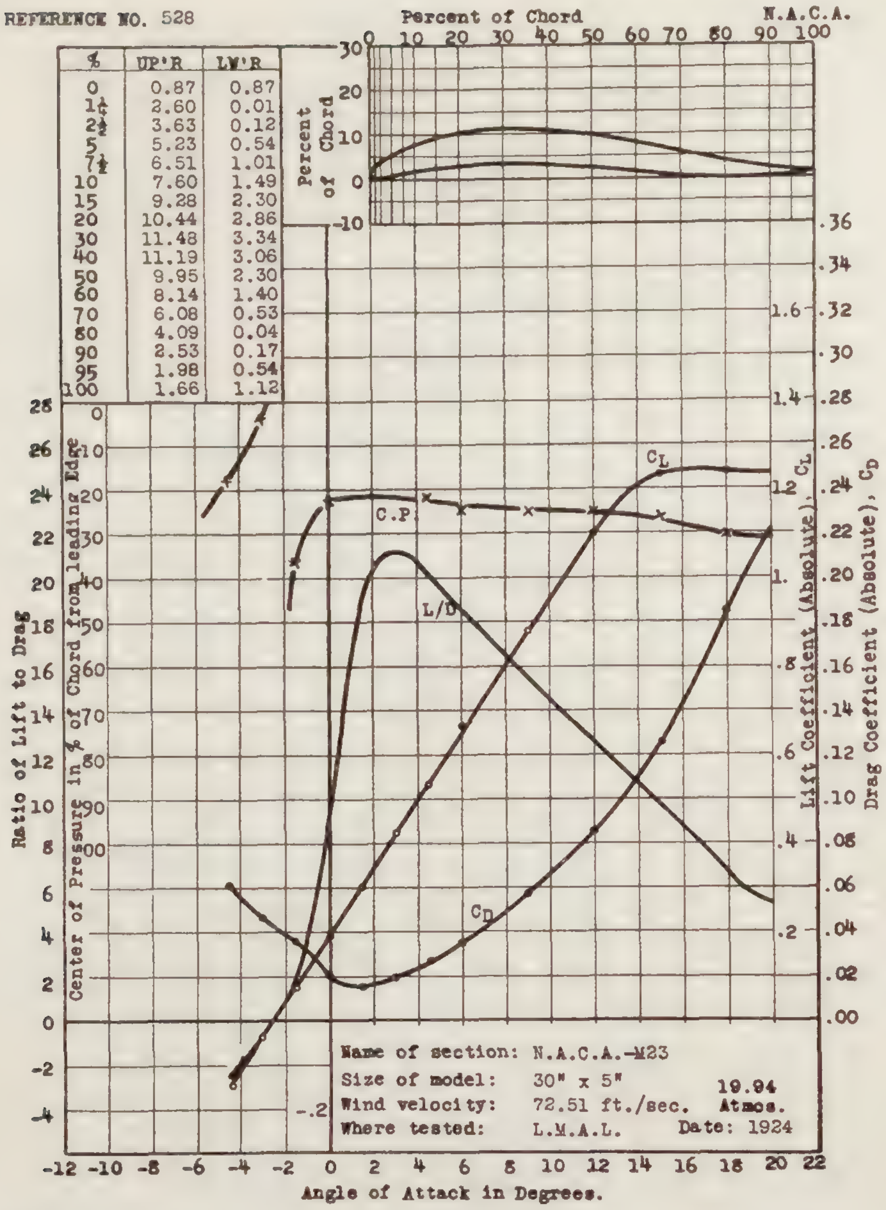


%	UP'R	LW'R
0	0.72	0.72
1¼	2.11	0.02
2½	2.98	0.22
5	4.45	0.79
7½	5.60	1.38
10	6.66	1.92
15	8.22	2.84
20	9.31	3.48
30	10.25	4.00
40	9.94	3.73
50	8.75	2.88
60	7.06	1.85
70	5.14	0.84
80	3.36	0.16
90	1.97	0.06
95	1.53	0.33
100	1.32	0.79

Name of section: N.A.C.A.-M22
Size of model: 30" x 5" 19.6 Atmos.
Wind velocity: 74.8 Ft./sec.
Where tested: L.M.A.L. Date: 1924

REFERENCE NO. 528

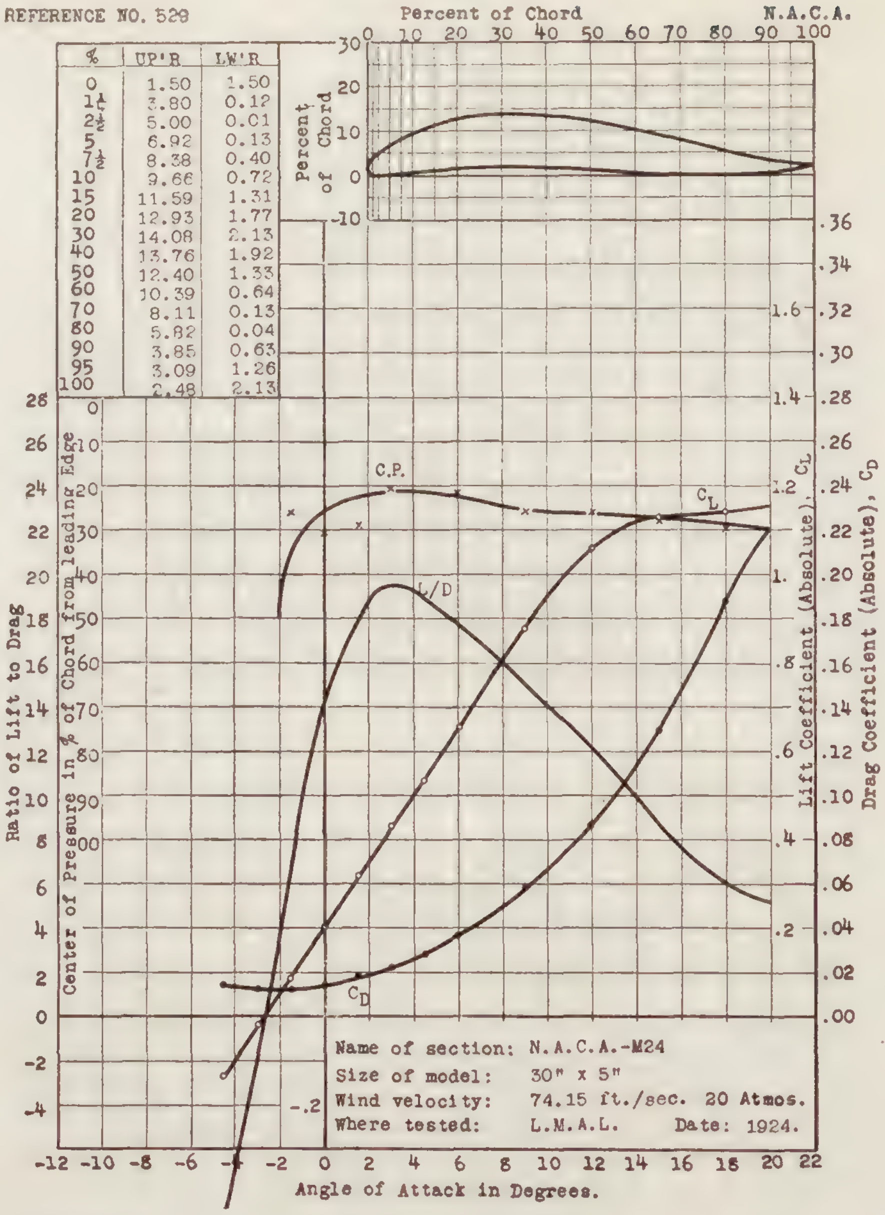
%	UP'R	LW'R
0	0.87	0.87
1¼	2.60	0.01
2½	3.63	0.12
5	5.23	0.54
7½	6.51	1.01
10	7.60	1.49
15	9.28	2.30
20	10.44	2.86
30	11.48	3.34
40	11.19	3.06
50	9.95	2.30
60	8.14	1.40
70	6.08	0.53
80	4.09	0.04
90	2.53	0.17
95	1.98	0.54
100	1.66	1.12



Name of section: N.A.C.A.-M23
Size of model: 30" x 5"
Wind velocity: 72.51 ft./sec. 19.94 Atmos.
Where tested: L.M.A.L. Date: 1924

REFERENCE NO. 529

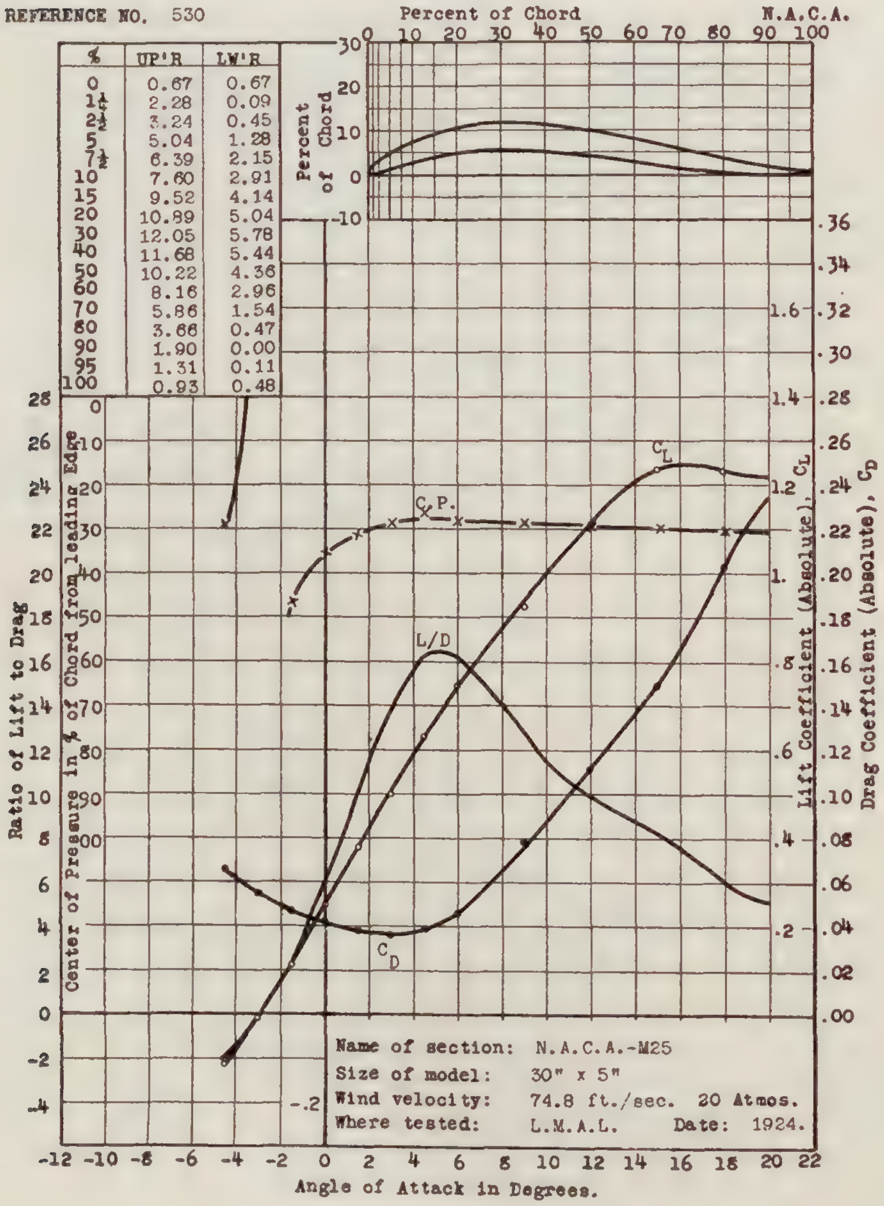
%	UP'R	LW'R
0	1.50	1.50
1¼	3.80	0.12
2½	5.00	0.01
5	6.92	0.13
7½	8.38	0.40
10	9.66	0.72
15	11.59	1.31
20	12.93	1.77
30	14.08	2.13
40	13.76	1.92
50	12.40	1.33
60	10.39	0.64
70	8.11	0.13
80	5.82	0.04
90	3.85	0.63
95	3.09	1.26
100	2.48	2.13



Name of section: N.A.C.A.-M24
Size of model: 30" x 5"
Wind velocity: 74.15 ft./sec. 20 Atmos.
Where tested: L.M.A.L. Date: 1924.

REFERENCE NO. 530

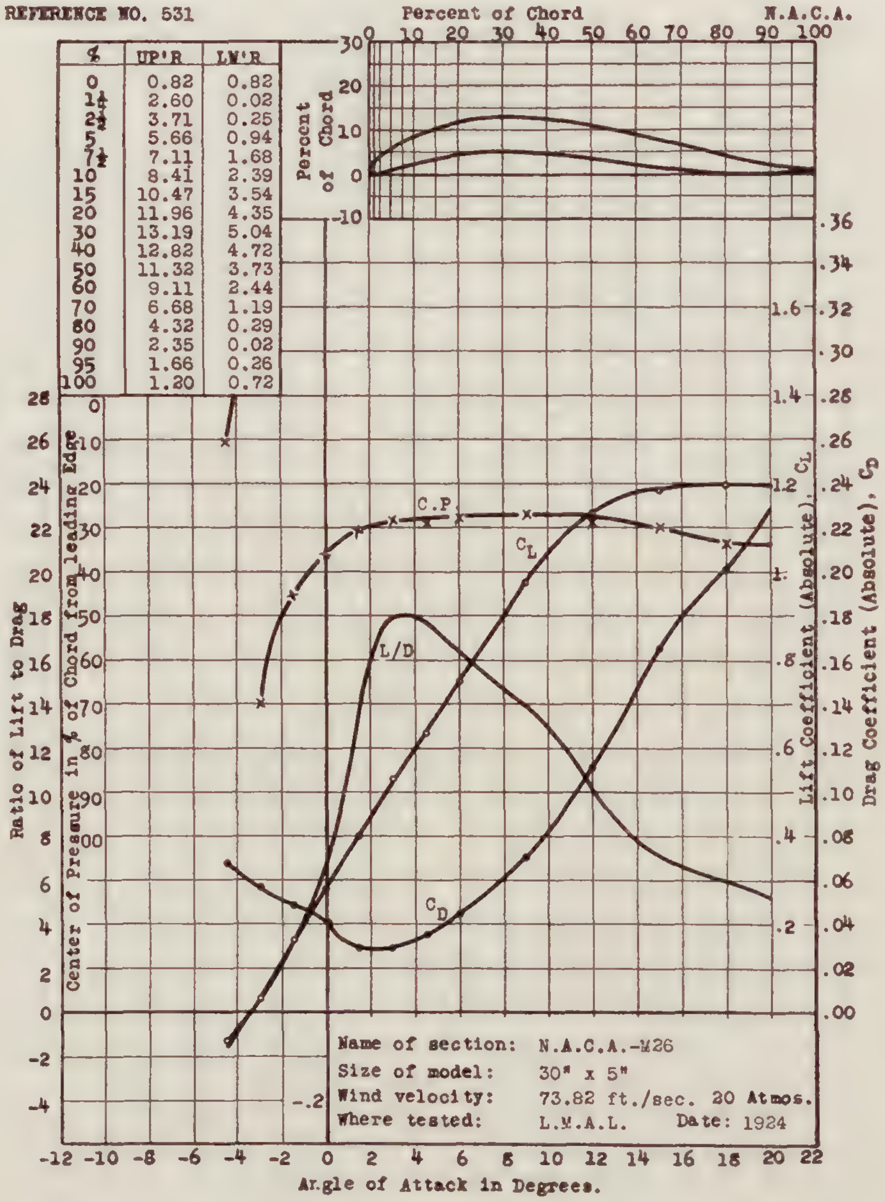
%	UP'R	LW'R
0	0.67	0.67
1¼	2.28	0.09
2½	3.24	0.45
5	5.04	1.28
7½	6.39	2.15
10	7.60	2.91
15	9.52	4.14
20	10.89	5.04
30	12.05	5.78
40	11.68	5.44
50	10.22	4.36
60	8.16	2.96
70	5.86	1.54
80	3.66	0.47
90	1.90	0.00
95	1.31	0.11
100	0.93	0.48



Name of section: N.A.C.A.-M25
Size of model: 30" x 5"
Wind velocity: 74.8 ft./sec. 20 Atmos.
Where tested: L.M.A.L. Date: 1924.

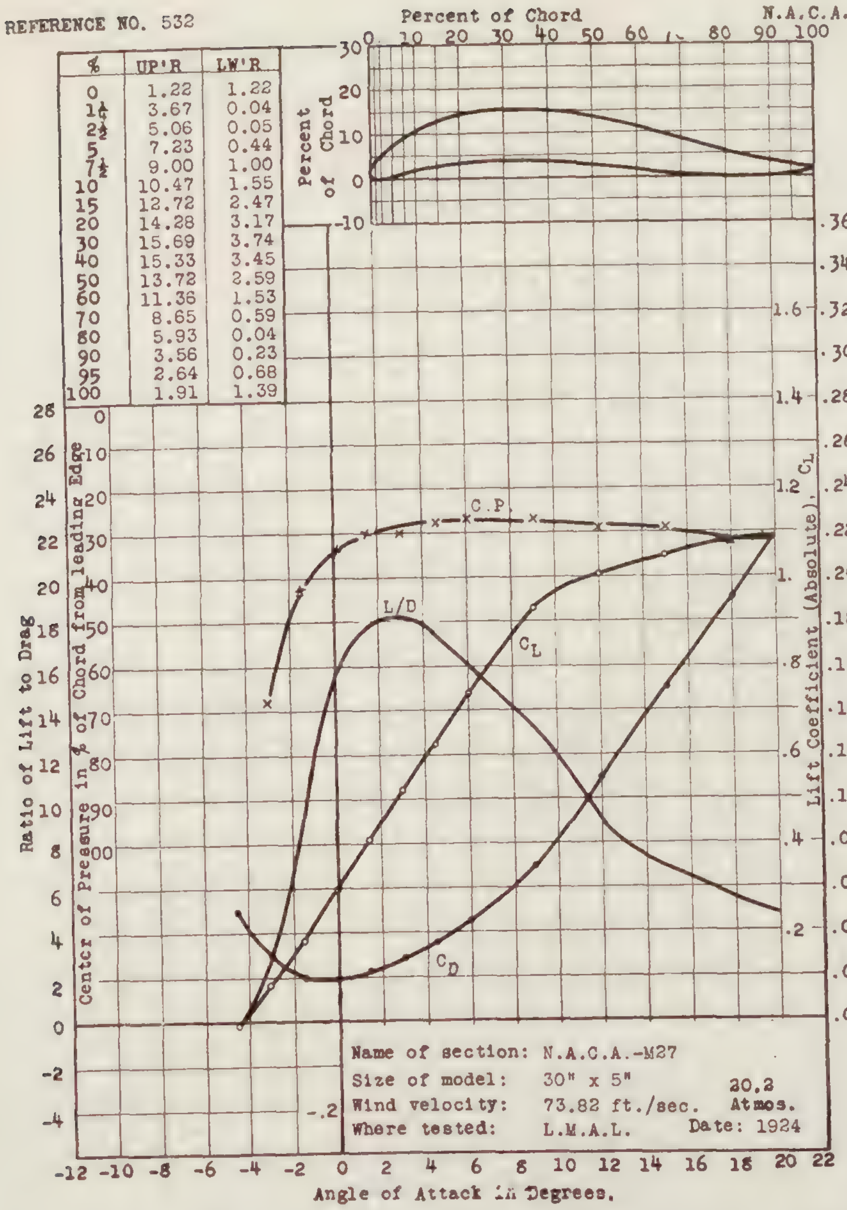
REFERENCE NO. 531

%	UP'R	LW'R
0	0.82	0.82
1¼	2.60	0.02
2½	3.71	0.25
5	5.66	0.94
7½	7.11	1.68
10	8.41	2.39
15	10.47	3.54
20	11.96	4.35
30	13.19	5.04
40	12.82	4.72
50	11.32	3.73
60	9.11	2.44
70	6.68	1.19
80	4.32	0.29
90	2.35	0.02
95	1.66	0.26
100	1.20	0.72



Name of section: N.A.C.A.-M26
Size of model: 30" x 5"
Wind velocity: 73.82 ft./sec. 20 Atmos.
Where tested: L.M.A.L. Date: 1924

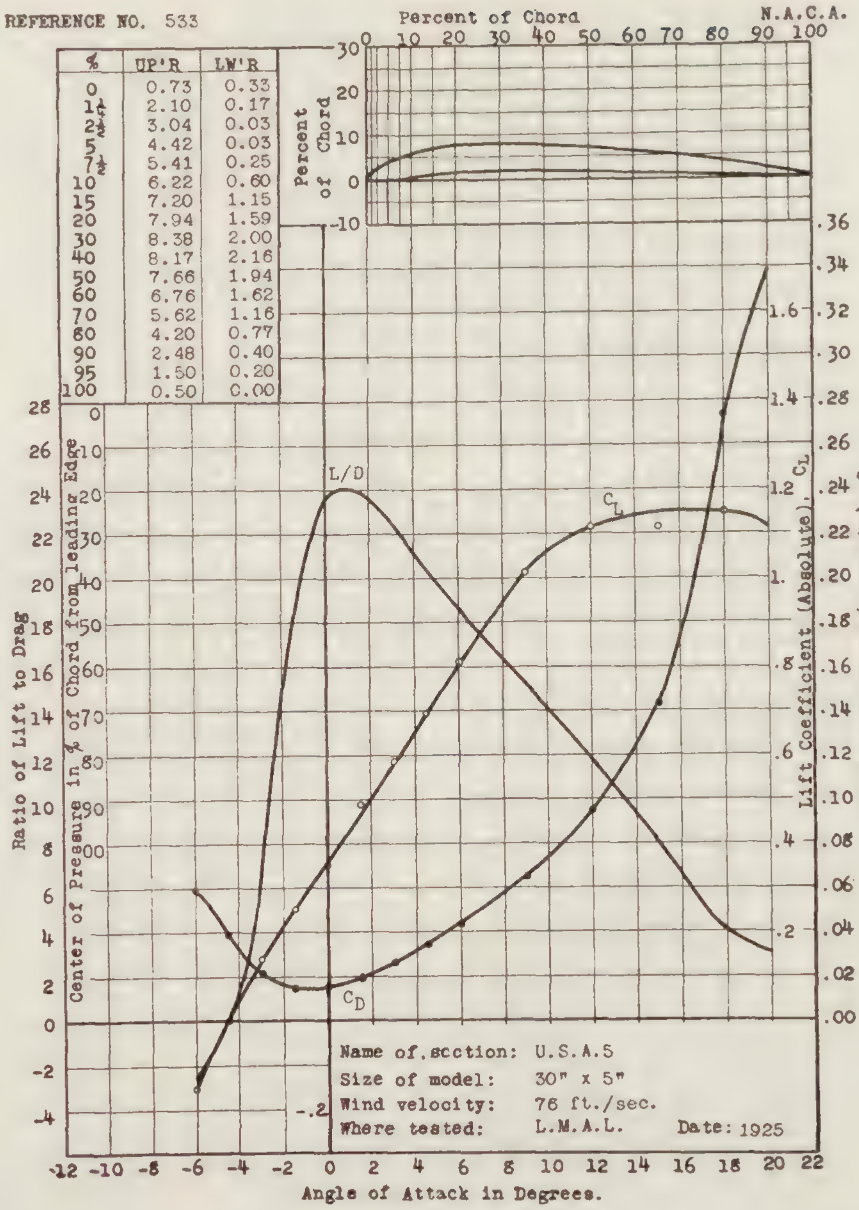
REFERENCE NO. 532



%	UP'R	LW'R
0	1.22	1.22
1¼	3.67	0.04
2½	5.06	0.05
5	7.23	0.44
7½	9.00	1.00
10	10.47	1.55
15	12.72	2.47
20	14.28	3.17
30	15.69	3.74
40	15.33	3.45
50	13.72	2.59
60	11.36	1.53
70	8.65	0.59
80	5.93	0.04
90	3.56	0.23
95	2.64	0.68
100	1.91	1.39

Name of section: N.A.C.A.-M27
Size of model: 30" x 5"
Wind velocity: 73.82 ft./sec. 20.2 Atmos.
Where tested: L.M.A.L. Date: 1924

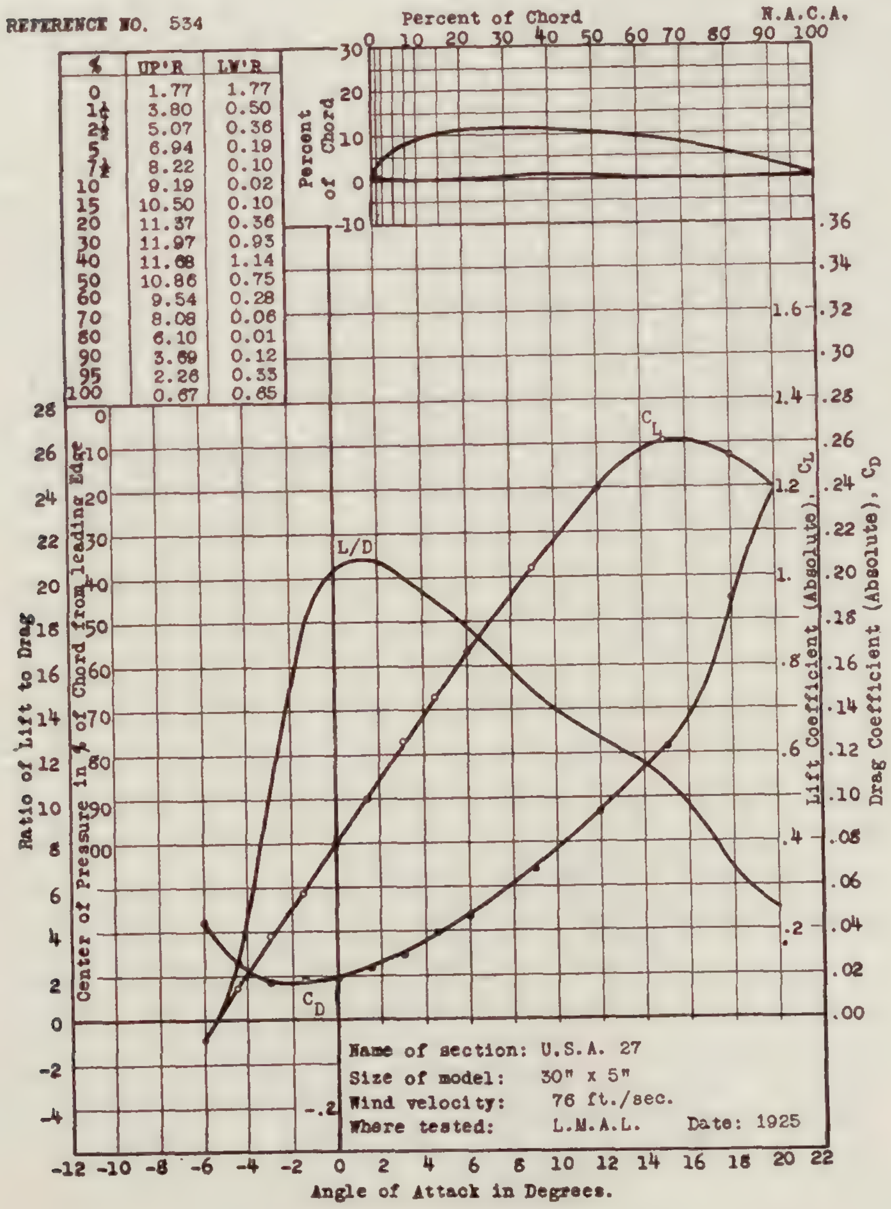
REFERENCE NO. 533



%	UP'R	LW'R
0	0.73	0.33
1¼	2.10	0.17
2½	3.04	0.03
5	4.42	0.03
7½	5.41	0.25
10	6.22	0.60
15	7.20	1.15
20	7.94	1.59
30	8.38	2.00
40	8.17	2.16
50	7.66	1.94
60	6.76	1.62
70	5.62	1.16
80	4.20	0.77
90	2.48	0.40
95	1.50	0.20
100	0.50	0.00

Name of section: U.S.A.5
Size of model: 30" x 5"
Wind velocity: 76 ft./sec.
Where tested: L.M.A.L. Date: 1925

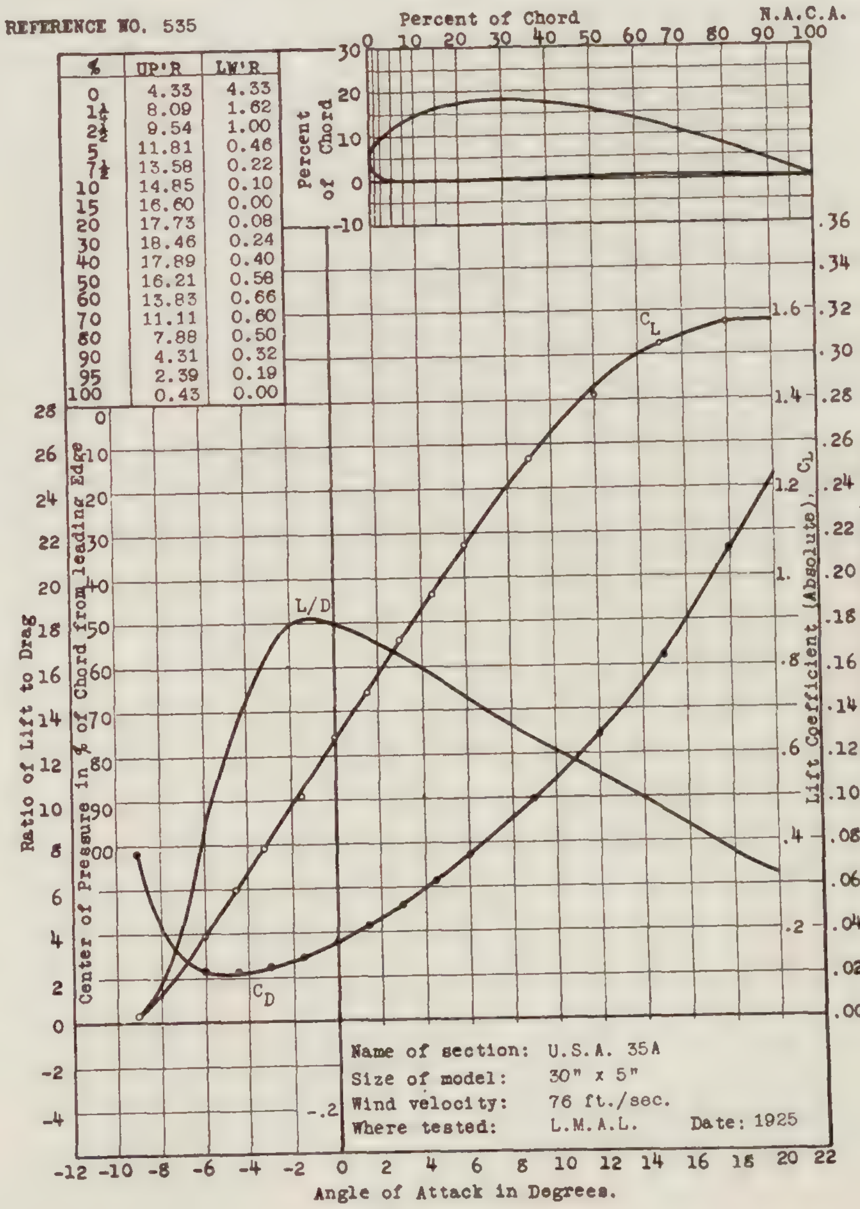
REFERENCE NO. 534



%	UP'R	LW'R
0	1.77	1.77
1¼	3.80	0.50
2½	5.07	0.36
5	6.94	0.19
7½	8.22	0.10
10	9.19	0.02
15	10.50	0.10
20	11.37	0.36
30	11.97	0.93
40	11.68	1.14
50	10.86	0.75
60	9.54	0.28
70	8.08	0.06
80	6.10	0.01
90	3.69	0.12
95	2.26	0.33
100	0.67	0.65

Name of section: U.S.A. 27
Size of model: 30" x 5"
Wind velocity: 76 ft./sec.
Where tested: L.M.A.L. Date: 1925

REFERENCE NO. 535

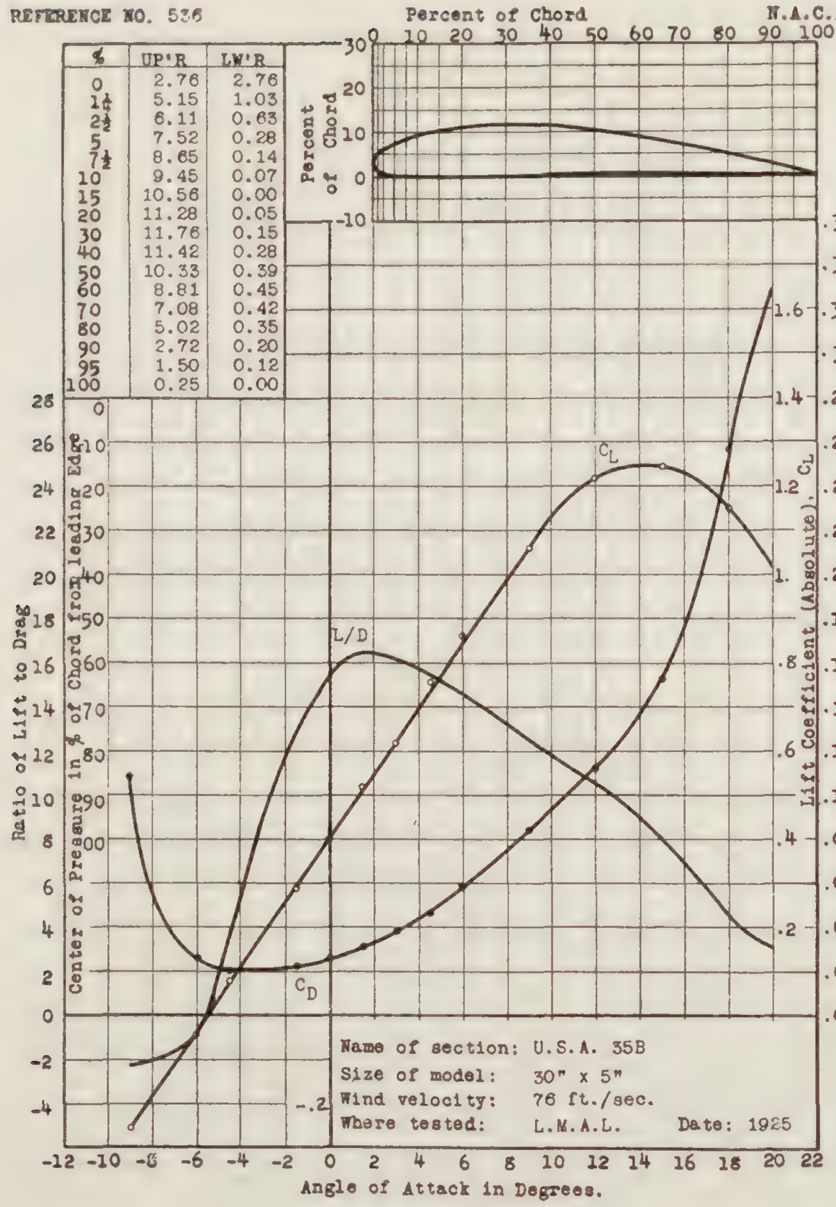


%	UP'R	LW'R
0	4.33	4.33
1¼	8.09	1.62
2½	9.54	1.00
5	11.81	0.46
7½	13.58	0.22
10	14.85	0.10
15	16.60	0.00
20	17.73	0.08
30	18.46	0.24
40	17.89	0.40
50	16.21	0.58
60	13.83	0.66
70	11.11	0.60
80	7.88	0.50
90	4.31	0.32
95	2.39	0.19
100	0.43	0.00

Name of section: U.S.A. 35A
Size of model: 30" x 5"
Wind velocity: 76 ft./sec.
Where tested: L.M.A.L. Date: 1925

REFERENCE NO. 536 N.A.C.A.

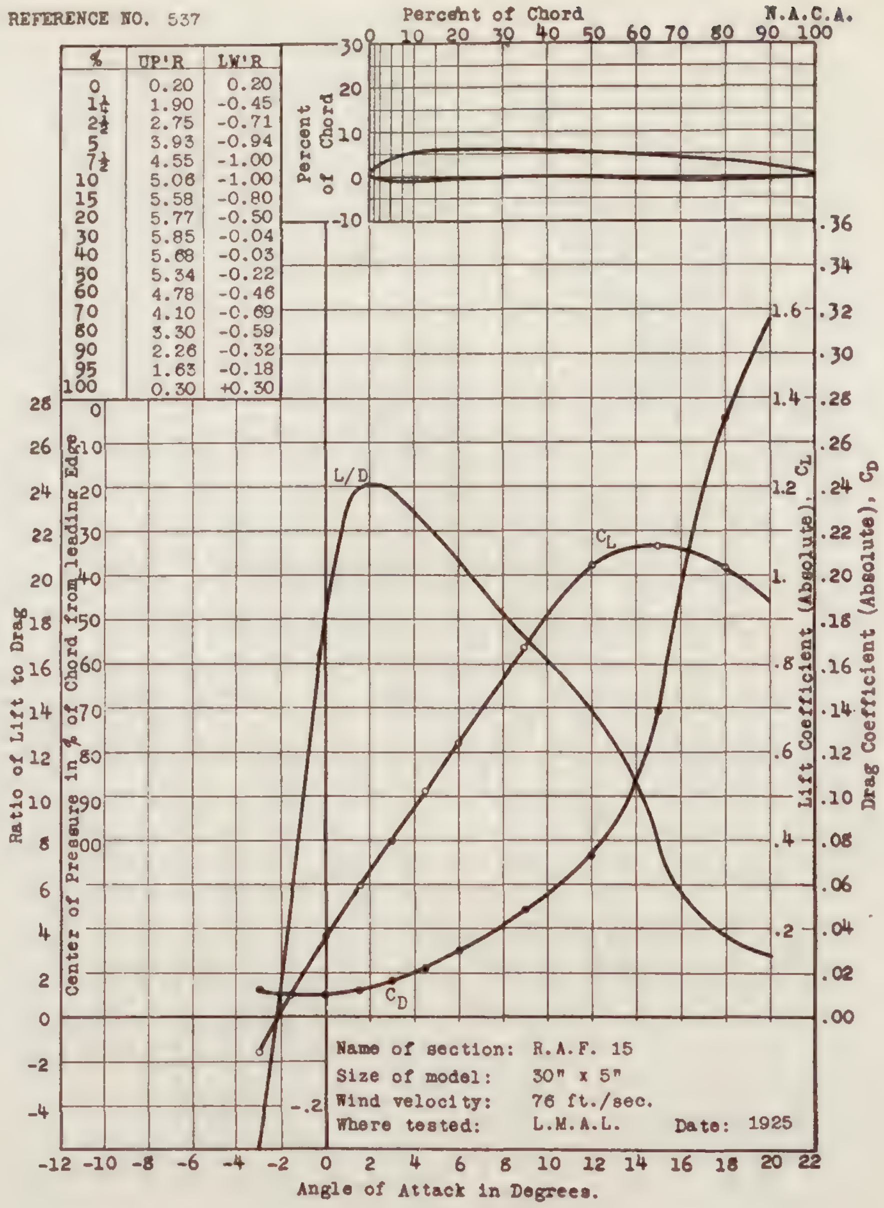
%	UP'R	LW'R
0	2.76	2.76
1¼	5.15	1.03
2½	6.11	0.63
5	7.52	0.28
7½	8.65	0.14
10	9.45	0.07
15	10.56	0.00
20	11.28	0.05
30	11.76	0.15
40	11.42	0.28
50	10.33	0.39
60	8.81	0.45
70	7.08	0.42
80	5.02	0.35
90	2.72	0.20
95	1.50	0.12
100	0.25	0.00



Name of section: U.S.A. 35B
Size of model: 30" x 5"
Wind velocity: 76 ft./sec.
Where tested: L.M.A.L. Date: 1925

REFERENCE NO. 537 N.A.C.A.

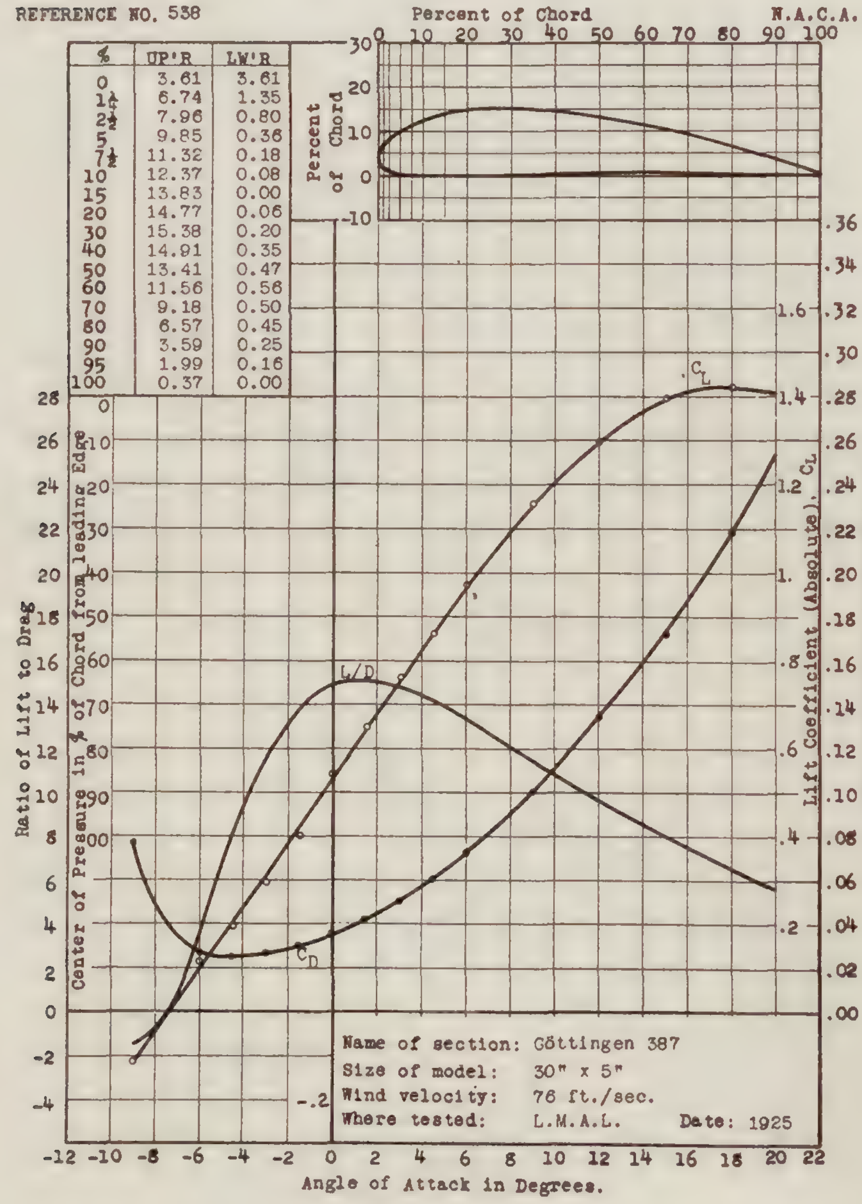
%	UP'R	LW'R
0	0.20	0.20
1¼	1.90	-0.45
2½	2.75	-0.71
5	3.93	-0.94
7½	4.55	-1.00
10	5.06	-1.00
15	5.58	-0.80
20	5.77	-0.50
30	5.85	-0.04
40	5.68	-0.03
50	5.34	-0.22
60	4.78	-0.46
70	4.10	-0.69
80	3.30	-0.59
90	2.26	-0.32
95	1.63	-0.18
100	0.30	+0.30



Name of section: R.A.F. 15
Size of model: 30" x 5"
Wind velocity: 76 ft./sec.
Where tested: L.M.A.L. Date: 1925

REFERENCE NO. 538 N.A.C.A.

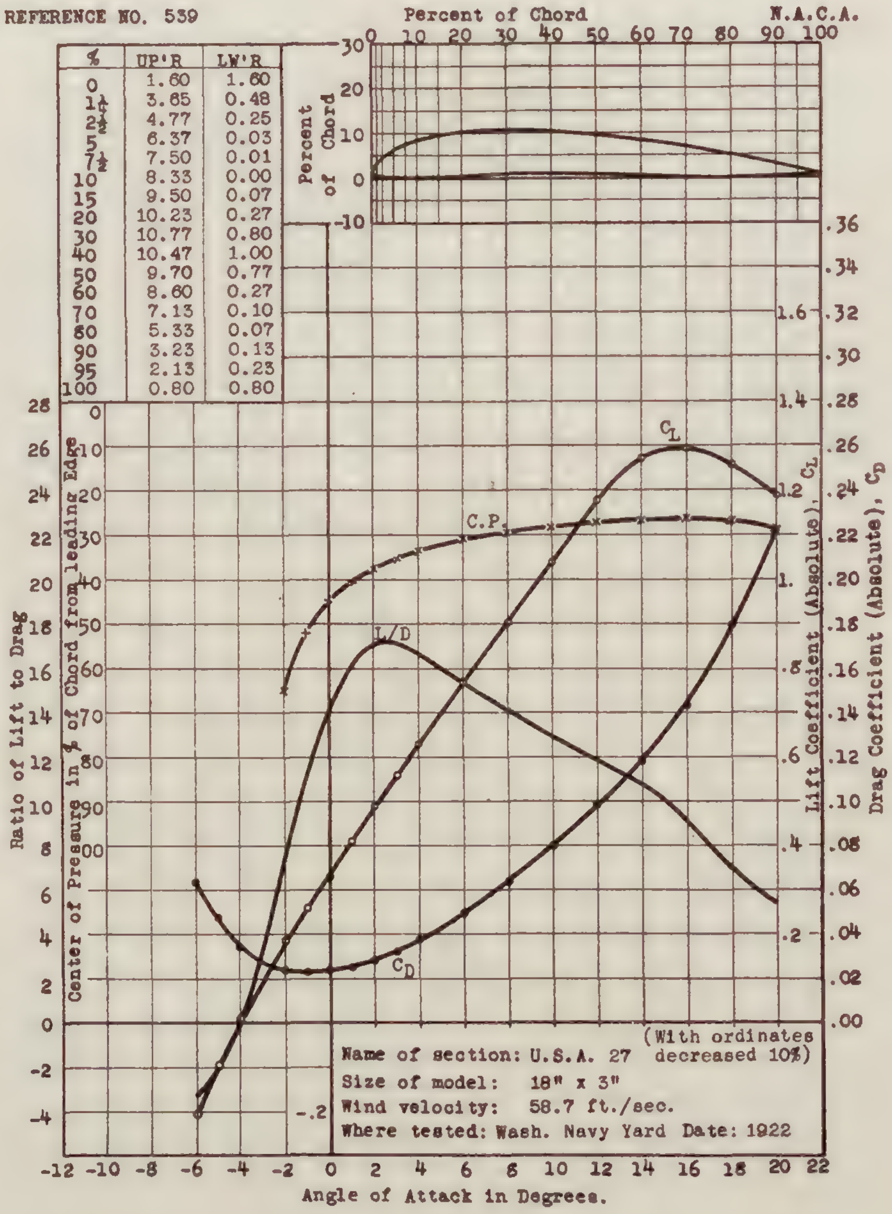
%	UP'R	LW'R
0	3.61	3.61
1¼	6.74	1.35
2½	7.96	0.80
5	9.85	0.36
7½	11.32	0.18
10	12.37	0.08
15	13.83	0.00
20	14.77	0.06
30	15.38	0.20
40	14.91	0.35
50	13.41	0.47
60	11.56	0.56
70	9.18	0.50
80	6.57	0.45
90	3.59	0.25
95	1.99	0.16
100	0.37	0.00



Name of section: Göttingen 387
Size of model: 30" x 5"
Wind velocity: 76 ft./sec.
Where tested: L.M.A.L. Date: 1925

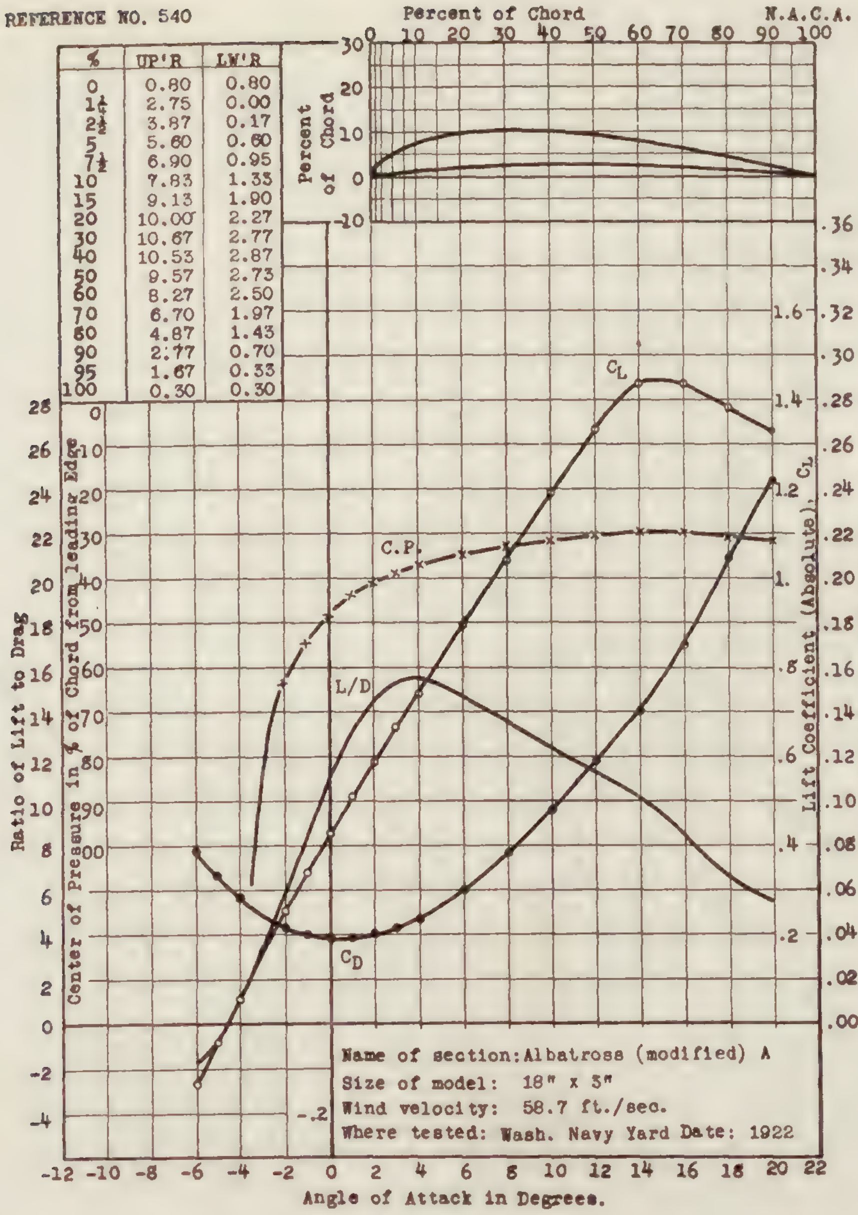
REFERENCE NO. 539 N.A.C.A.

%	UP'R	LW'R
0	1.60	1.60
1¼	3.65	0.48
2½	4.77	0.25
5	6.37	0.03
7½	7.50	0.01
10	8.33	0.00
15	9.50	0.07
20	10.23	0.27
30	10.77	0.80
40	10.47	1.00
50	9.70	0.77
60	8.60	0.27
70	7.13	0.10
80	5.33	0.07
90	3.23	0.13
95	2.13	0.23
100	0.80	0.80



Name of section: U.S.A. 27 (With ordinates decreased 10%)
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1922

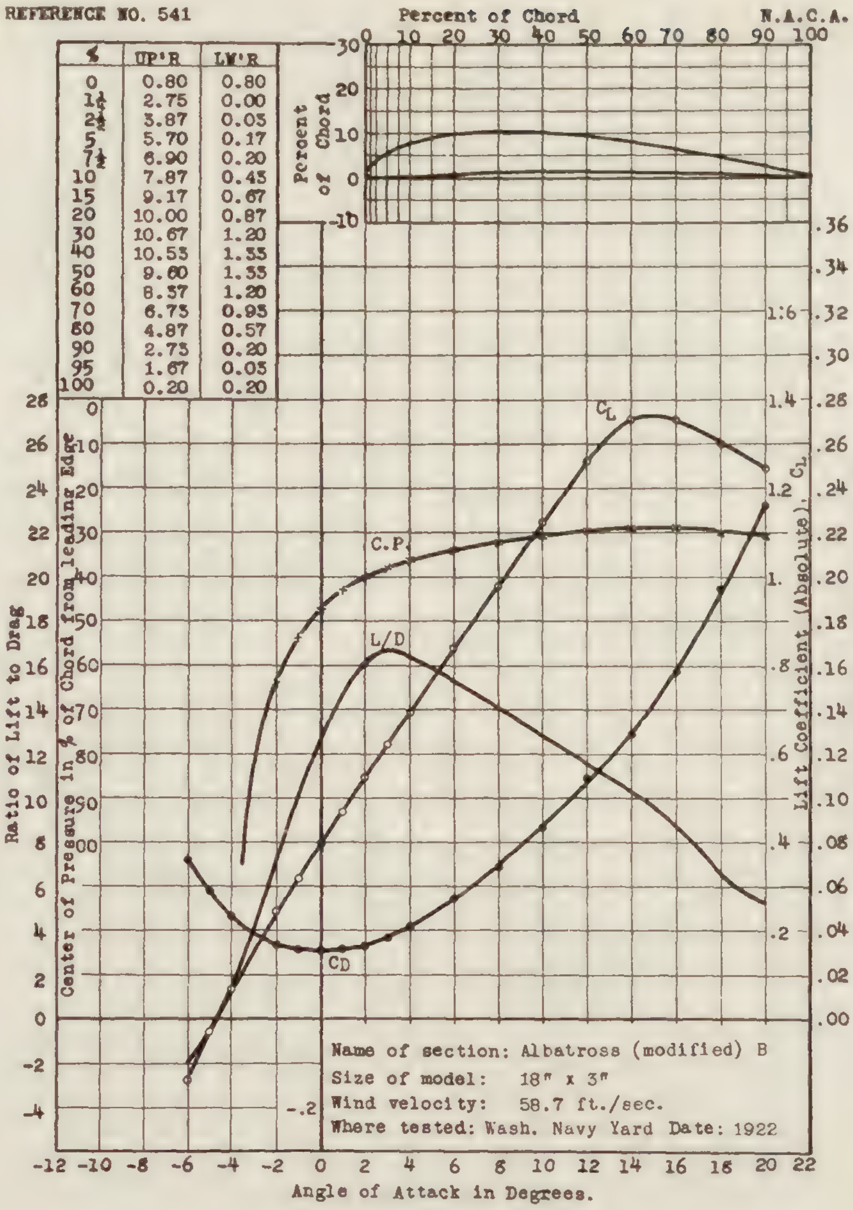
REFERENCE NO. 540



%	UP'R	LW'R
0	0.80	0.80
1¼	2.75	0.00
2½	3.87	0.17
5	5.60	0.60
7½	6.90	0.95
10	7.83	1.33
15	9.13	1.90
20	10.00	2.27
30	10.67	2.77
40	10.53	2.87
50	9.57	2.73
60	8.27	2.50
70	6.70	1.97
80	4.87	1.43
90	2.77	0.70
95	1.67	0.33
100	0.30	0.30

Name of section: Albatross (modified) A
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1922

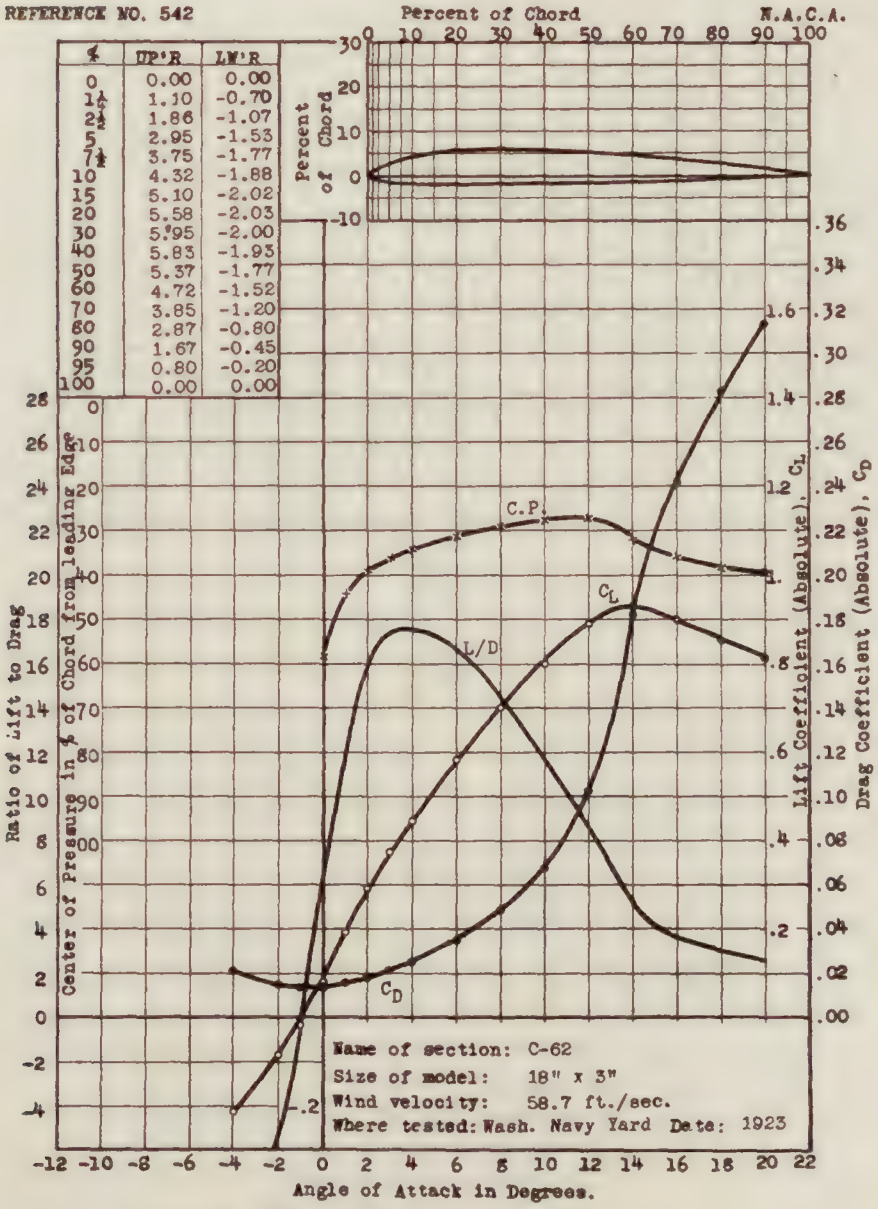
REFERENCE NO. 541



%	UP'R	LW'R
0	0.80	0.80
1¼	2.75	0.00
2½	3.87	0.05
5	5.70	0.17
7½	6.90	0.20
10	7.87	0.45
15	9.17	0.67
20	10.00	0.87
30	10.67	1.20
40	10.53	1.33
50	9.60	1.33
60	8.57	1.20
70	6.73	0.93
80	4.87	0.57
90	2.73	0.20
95	1.67	0.05
100	0.20	0.20

Name of section: Albatross (modified) B
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1922

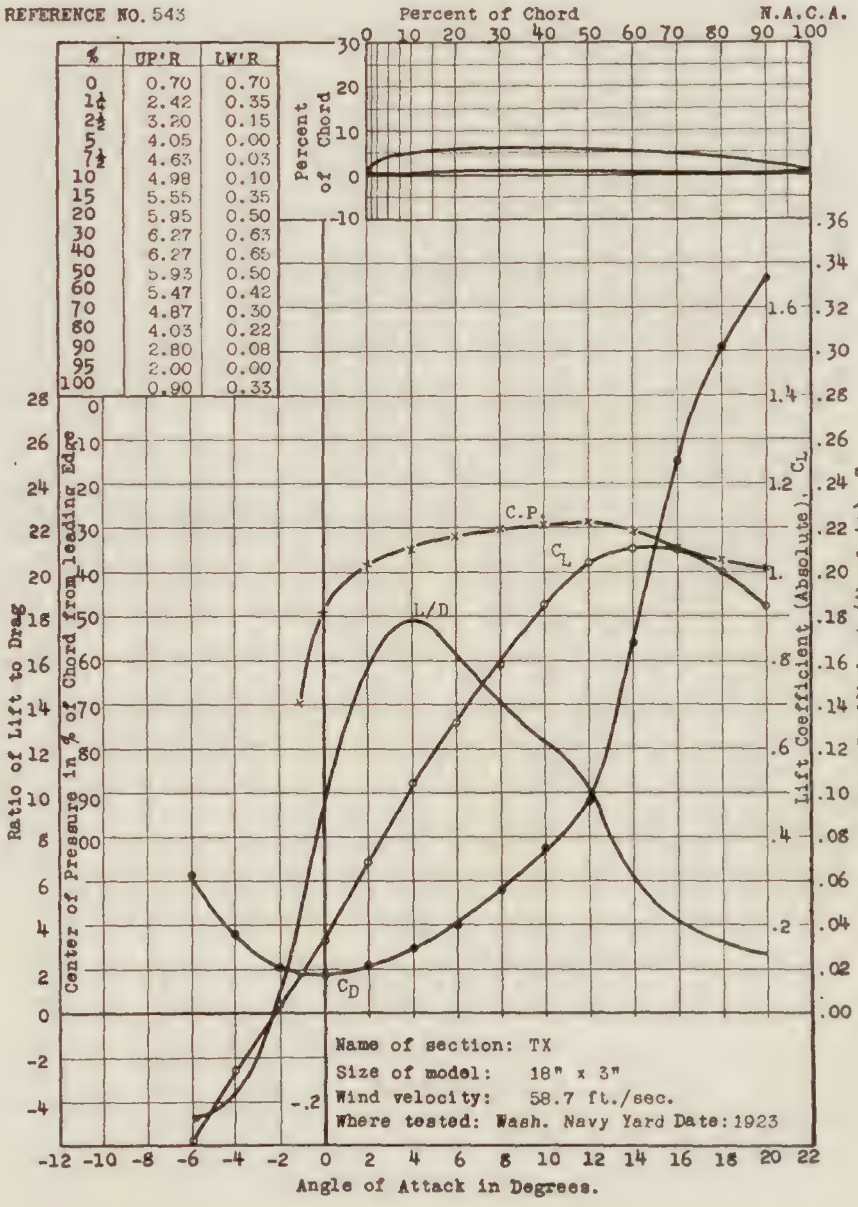
REFERENCE NO. 542



%	UP'R	LW'R
0	0.00	0.00
1¼	1.10	-0.70
2½	1.86	-1.07
5	2.95	-1.53
7½	3.75	-1.77
10	4.32	-1.88
15	5.10	-2.02
20	5.58	-2.03
30	5.95	-2.00
40	5.83	-1.93
50	5.37	-1.77
60	4.72	-1.52
70	3.85	-1.20
80	2.87	-0.80
90	1.67	-0.45
95	0.80	-0.20
100	0.00	0.00

Name of section: C-62
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1923

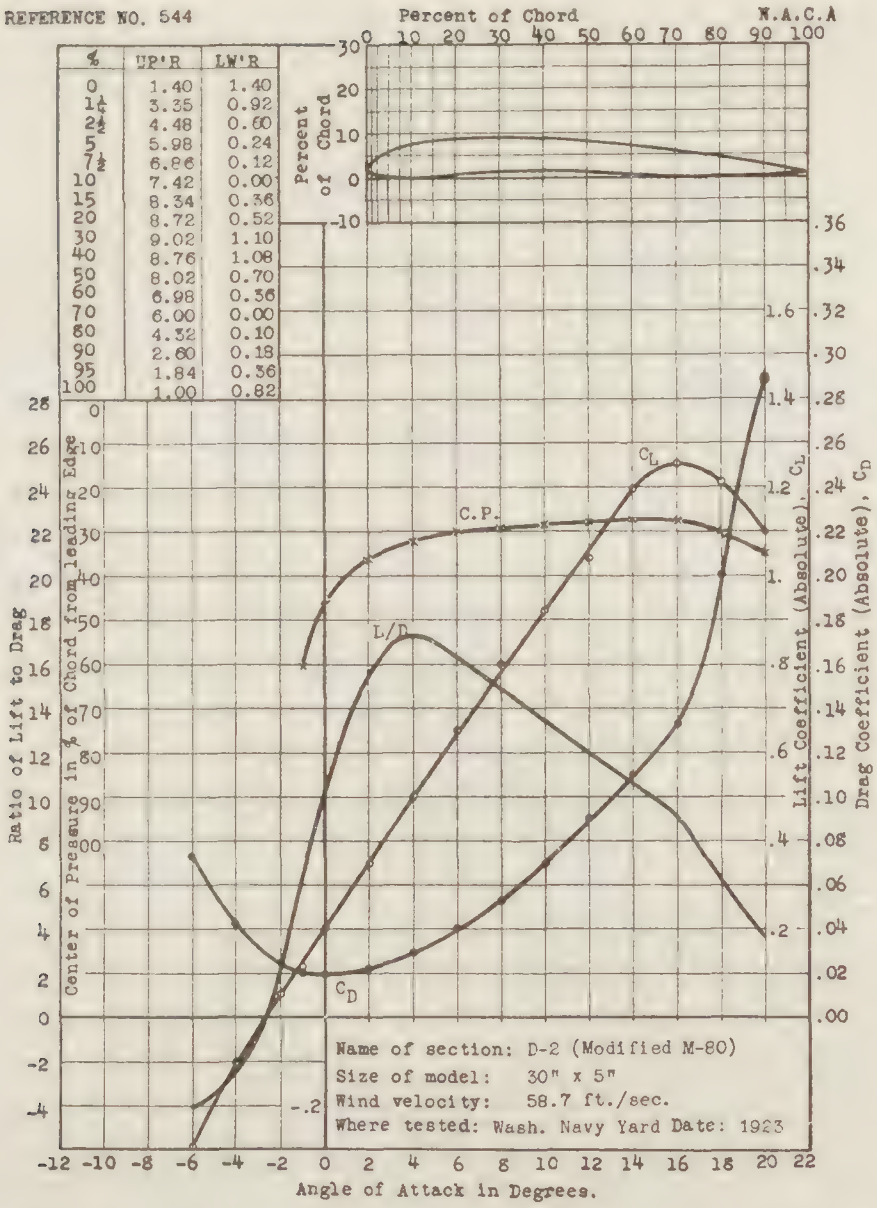
REFERENCE NO. 543



%	UP'R	LW'R
0	0.70	0.70
1¼	2.42	0.35
2½	3.20	0.15
5	4.05	0.00
7½	4.63	0.03
10	4.98	0.10
15	5.55	0.35
20	5.95	0.50
30	6.27	0.63
40	6.27	0.65
50	5.93	0.50
60	5.47	0.42
70	4.87	0.30
80	4.03	0.22
90	2.80	0.08
95	2.00	0.00
100	0.90	0.33

Name of section: TX
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1923

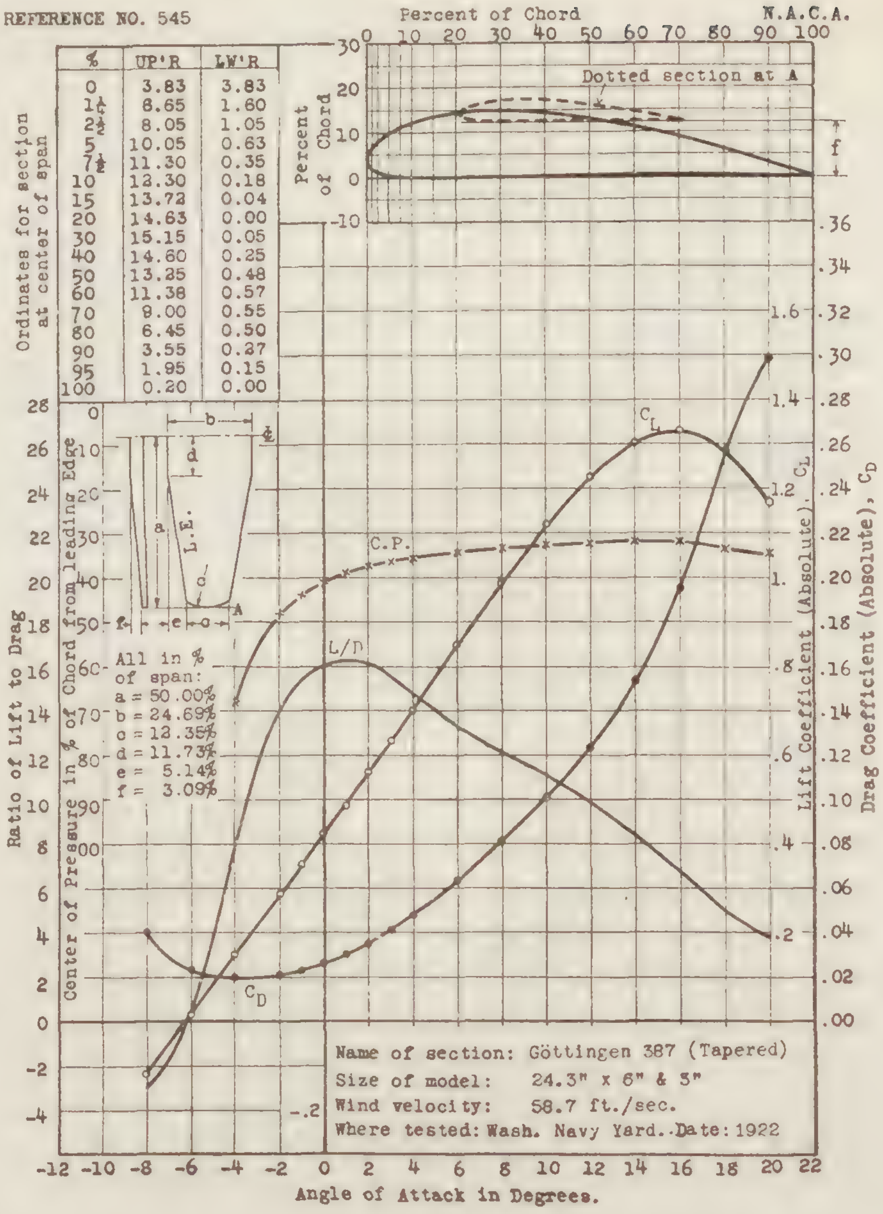
REFERENCE NO. 544



%	UP'R	LW'R
0	1.40	1.40
1¼	3.35	0.92
2½	4.48	0.60
5	5.98	0.24
7½	6.86	0.12
10	7.42	0.00
15	8.34	0.36
20	8.72	0.52
30	9.02	1.10
40	8.76	1.08
50	8.02	0.70
60	6.98	0.36
70	6.00	0.00
80	4.32	0.10
90	2.60	0.18
95	1.84	0.36
100	1.00	0.82

Name of section: D-2 (Modified M-80)
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1923

REFERENCE NO. 545



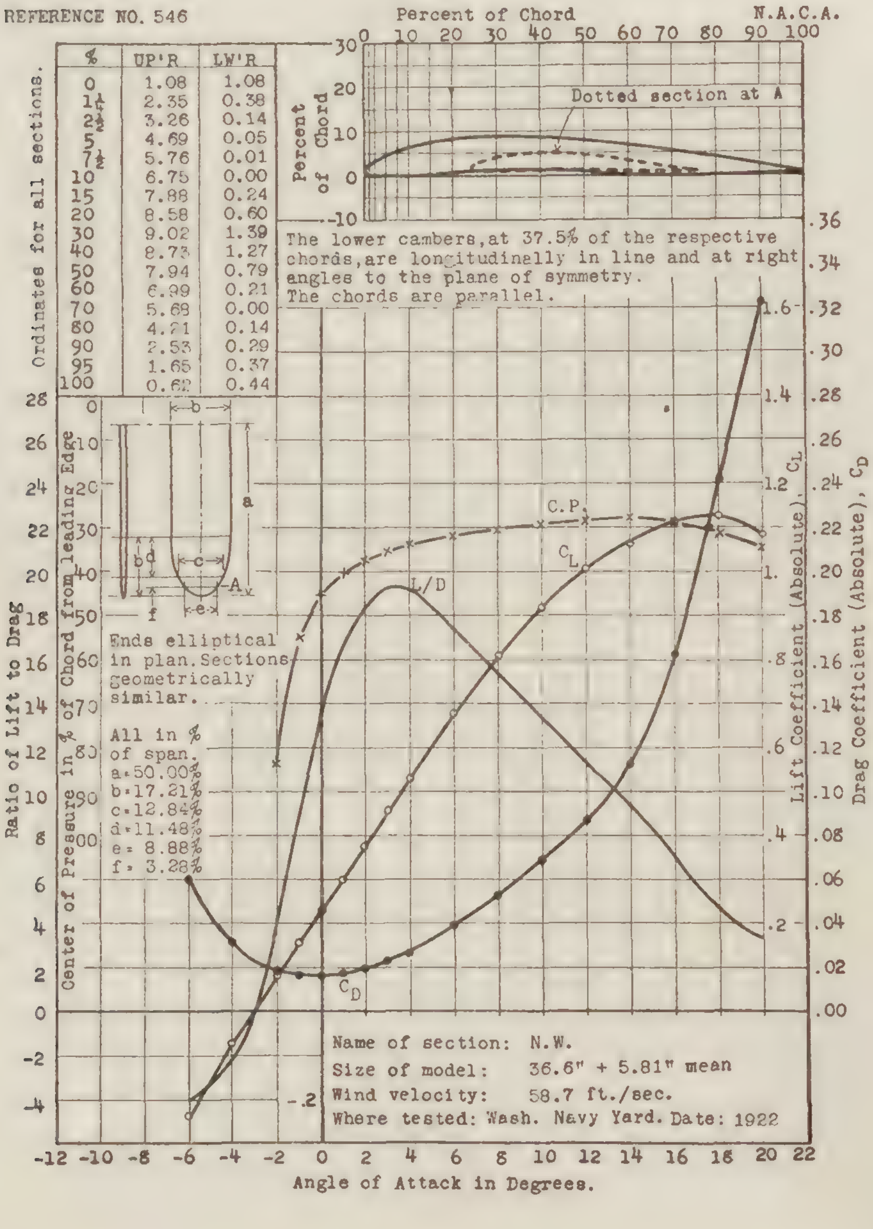
Ordinates for section at center of span

%	UP'R	LW'R
0	3.83	3.83
1¼	6.65	1.60
2½	8.05	1.05
5	10.05	0.63
7½	11.30	0.35
10	12.30	0.18
15	13.72	0.04
20	14.63	0.00
30	15.15	0.05
40	14.60	0.25
50	13.25	0.48
60	11.38	0.57
70	8.00	0.55
80	6.45	0.50
90	3.55	0.27
95	1.95	0.15
100	0.20	0.00

All in % of span:
a = 50.00%
b = 24.69%
c = 12.35%
d = 11.73%
e = 5.14%
f = 3.09%

Name of section: Göttingen 387 (Tapered)
Size of model: 24.3" x 6" & 3"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard. Date: 1922

REFERENCE NO. 546



Ordinates for all sections.

%	UP'R	LW'R
0	1.08	1.08
1¼	2.35	0.38
2½	3.26	0.14
5	4.69	0.05
7½	5.76	0.01
10	6.75	0.00
15	7.88	0.24
20	8.58	0.60
30	9.02	1.39
40	8.73	1.27
50	7.94	0.79
60	6.99	0.21
70	5.68	0.00
80	4.21	0.14
90	2.53	0.29
95	1.65	0.37
100	0.62	0.44

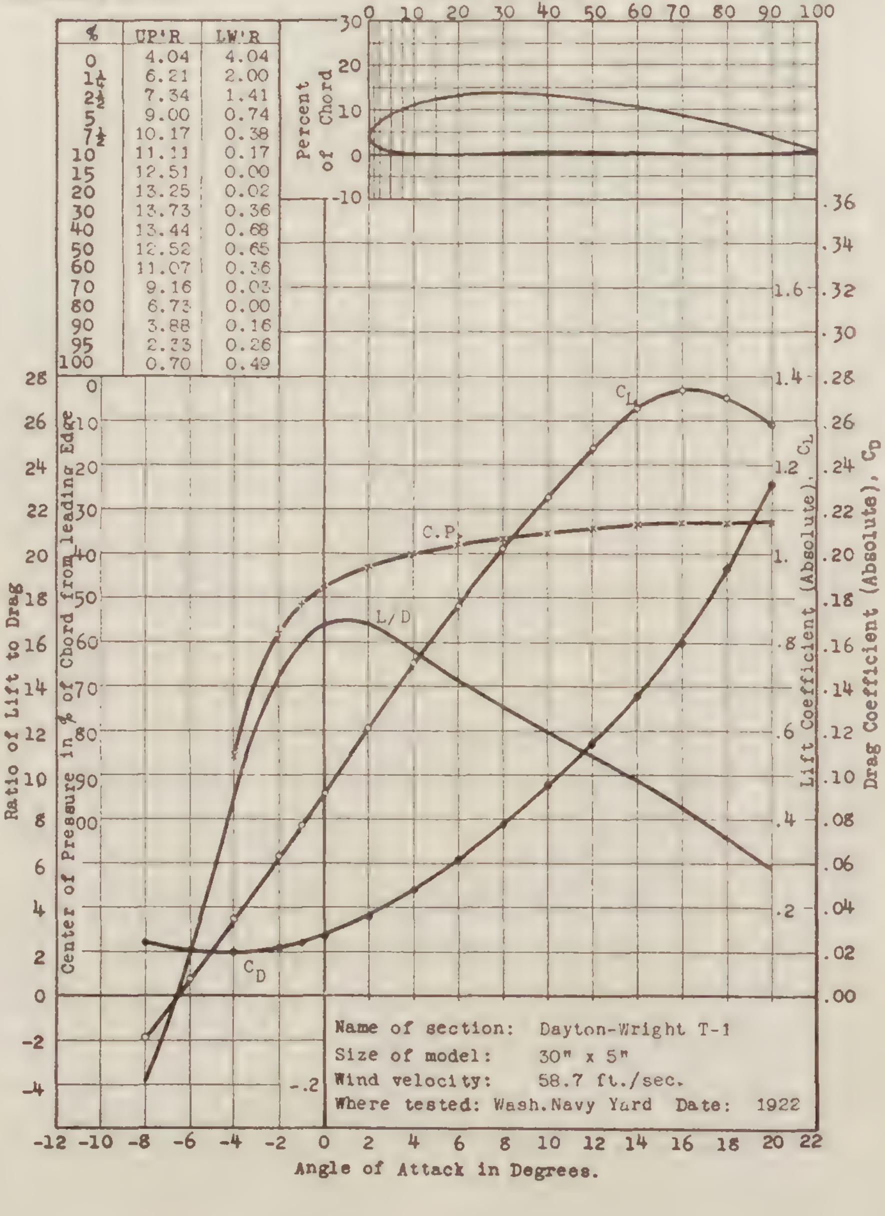
The lower cambers, at 37.5% of the respective chords, are longitudinally in line and at right angles to the plane of symmetry. The chords are parallel.

Ends elliptical in plan. Sections geometrically similar.

All in % of span.
a = 50.00%
b = 17.21%
c = 12.84%
d = 11.48%
e = 8.88%
f = 3.28%

Name of section: N.W.
Size of model: 36.6" + 5.81" mean
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard. Date: 1922

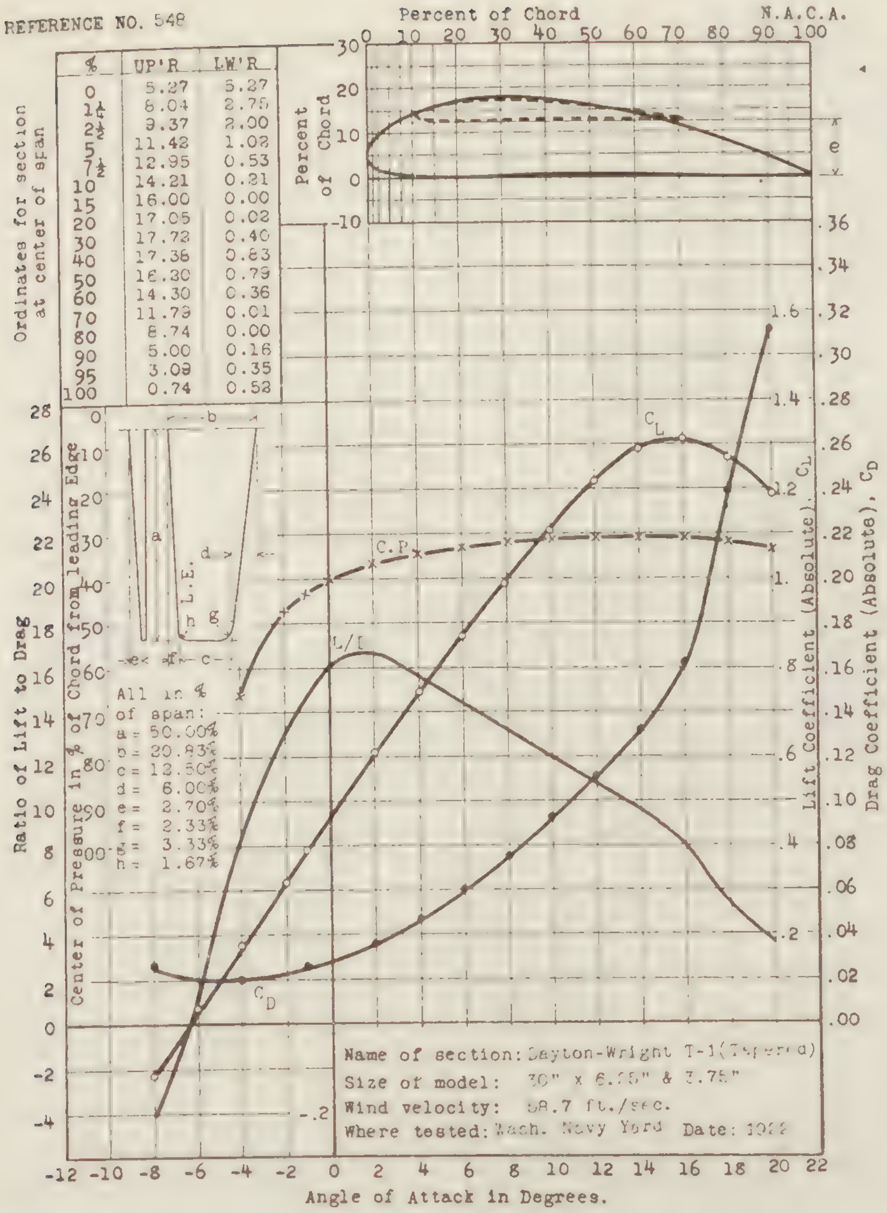
REFERENCE NO. 547



%	UP'R	LW'R
0	4.04	4.04
1¼	6.21	2.00
2½	7.34	1.41
5	9.00	0.74
7½	10.17	0.38
10	11.11	0.17
15	12.51	0.00
20	13.25	0.02
30	13.73	0.36
40	13.44	0.68
50	12.52	0.65
60	11.07	0.36
70	9.16	0.03
80	6.73	0.00
90	3.88	0.16
95	2.33	0.26
100	0.70	0.49

Name of section: Dayton-Wright T-1
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1922

REFERENCE NO. 548

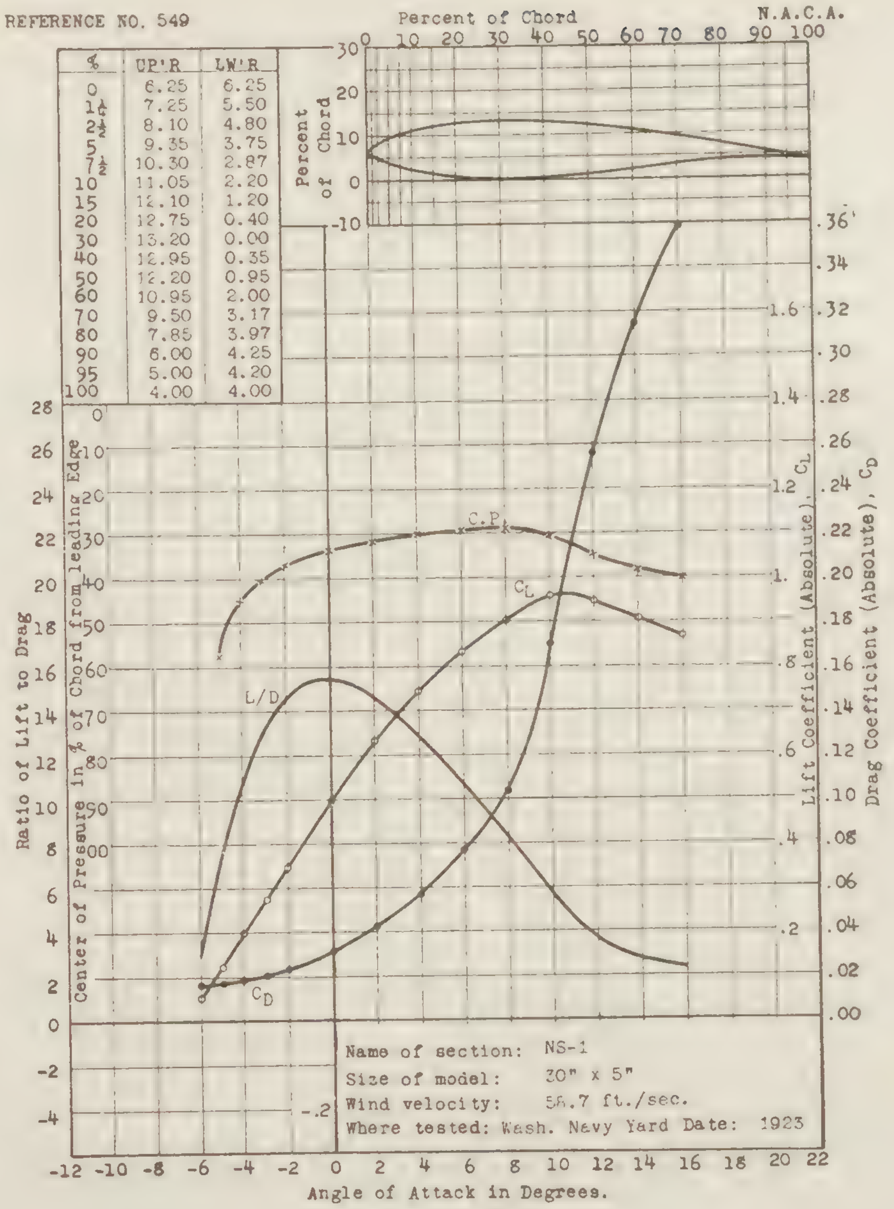


%	UP'R	LW'R
0	5.27	5.27
1¼	8.04	2.75
2½	9.37	2.00
5	11.42	1.02
7½	12.95	0.53
10	14.21	0.21
15	16.00	0.00
20	17.05	0.02
30	17.72	0.40
40	17.36	0.83
50	16.30	0.79
60	14.30	0.36
70	11.73	0.01
80	8.74	0.00
90	5.00	0.16
95	3.09	0.35
100	0.74	0.52

All in % of span:
a = 50.00%
b = 20.83%
c = 12.50%
d = 6.00%
e = 2.70%
f = 2.33%
g = 3.33%
h = 1.67%

Name of section: Dayton-Wright T-1(Tapered)
Size of model: 30" x 6.25" & 3.75"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1922

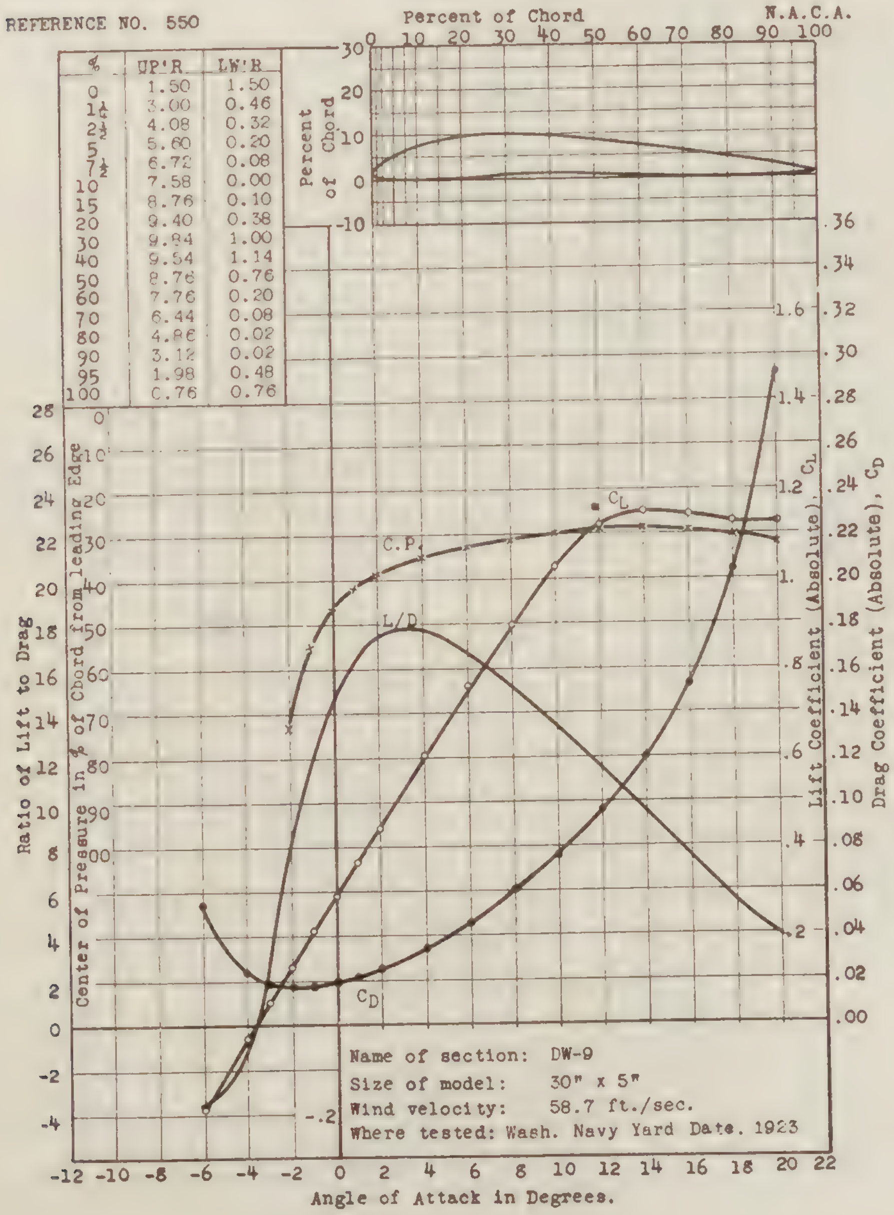
REFERENCE NO. 549



%	UP'R	LW'R
0	6.25	6.25
1¼	7.25	5.50
2½	8.10	4.80
5	9.35	3.75
7½	10.30	2.87
10	11.05	2.20
15	12.10	1.20
20	12.75	0.40
30	13.20	0.00
40	12.95	0.35
50	12.20	0.95
60	10.95	2.00
70	9.50	3.17
80	7.85	3.97
90	6.00	4.25
95	5.00	4.20
100	4.00	4.00

Name of section: NS-1
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1923

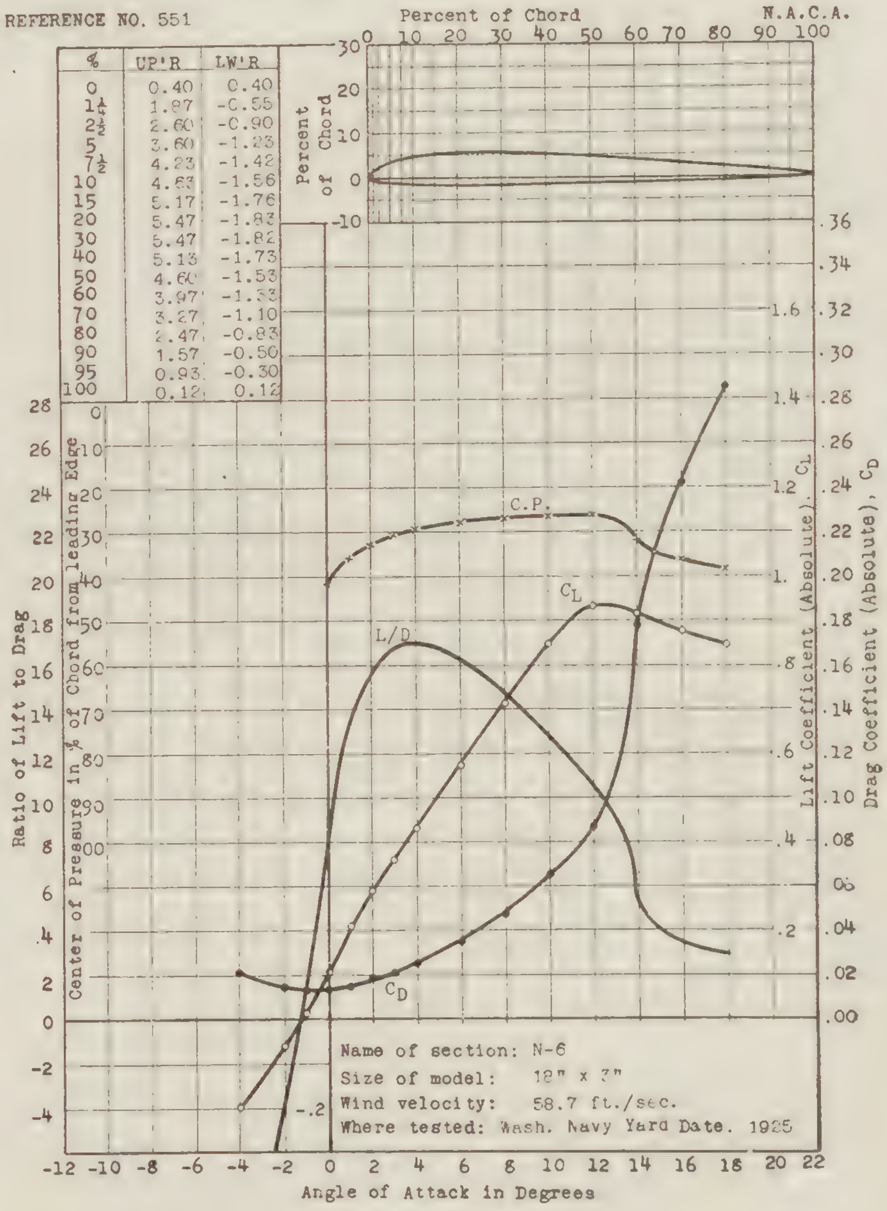
REFERENCE NO. 550



%	UP'R	LW'R
0	1.50	1.50
1¼	3.00	0.46
2½	4.08	0.32
5	5.60	0.20
7½	6.72	0.08
10	7.58	0.00
15	8.76	0.10
20	9.40	0.38
30	9.84	1.00
40	9.54	1.14
50	8.76	0.76
60	7.76	0.20
70	6.44	0.08
80	4.86	0.02
90	3.12	0.02
95	1.98	0.48
100	0.76	0.76

Name of section: DW-9
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date. 1923

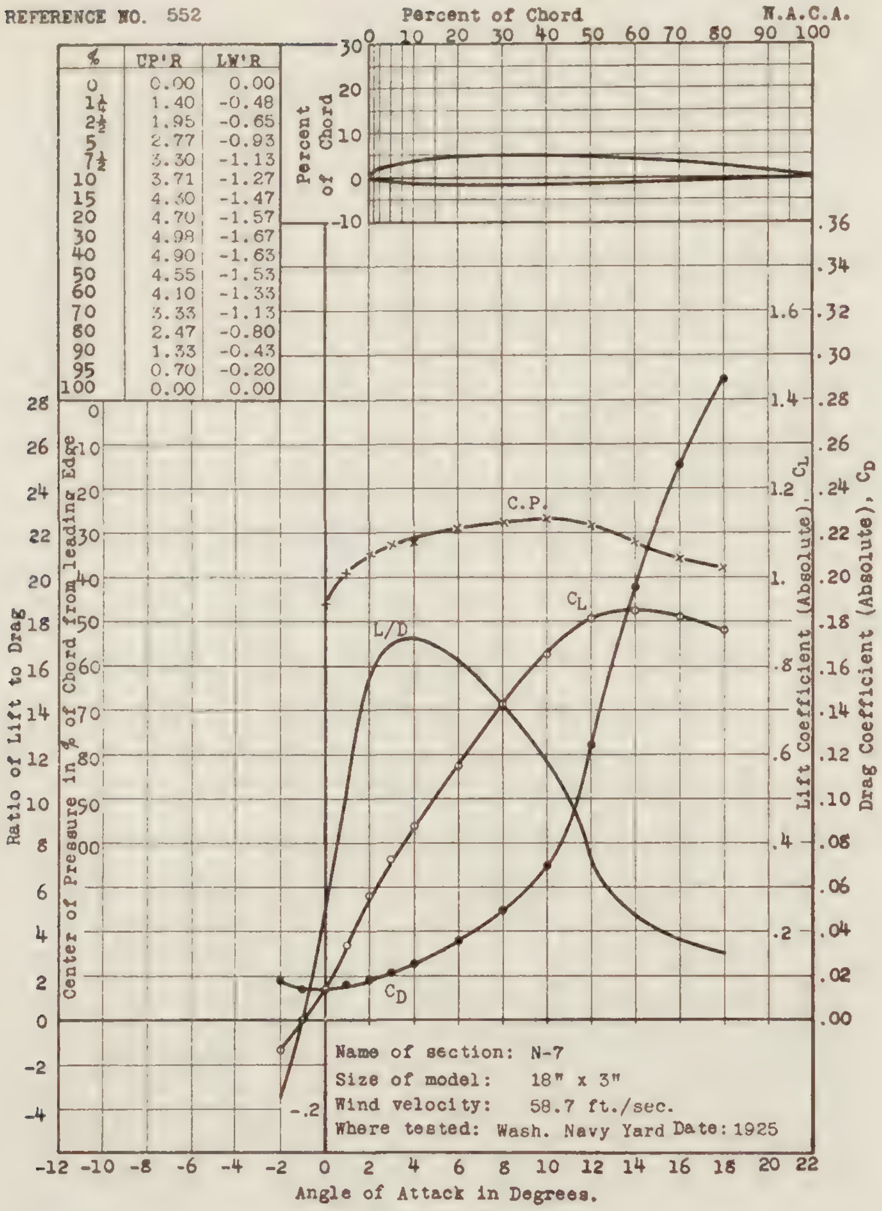
REFERENCE NO. 551



%	UP'R	LW'R
0	0.40	0.40
1¼	1.87	-0.55
2½	2.60	-0.90
5	3.60	-1.23
7½	4.23	-1.42
10	4.63	-1.56
15	5.17	-1.76
20	5.47	-1.83
30	5.47	-1.82
40	5.13	-1.73
50	4.60	-1.53
60	3.97	-1.33
70	3.27	-1.10
80	2.47	-0.83
90	1.57	-0.50
95	0.93	-0.30
100	0.12	0.12

Name of section: N-6
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date. 1925

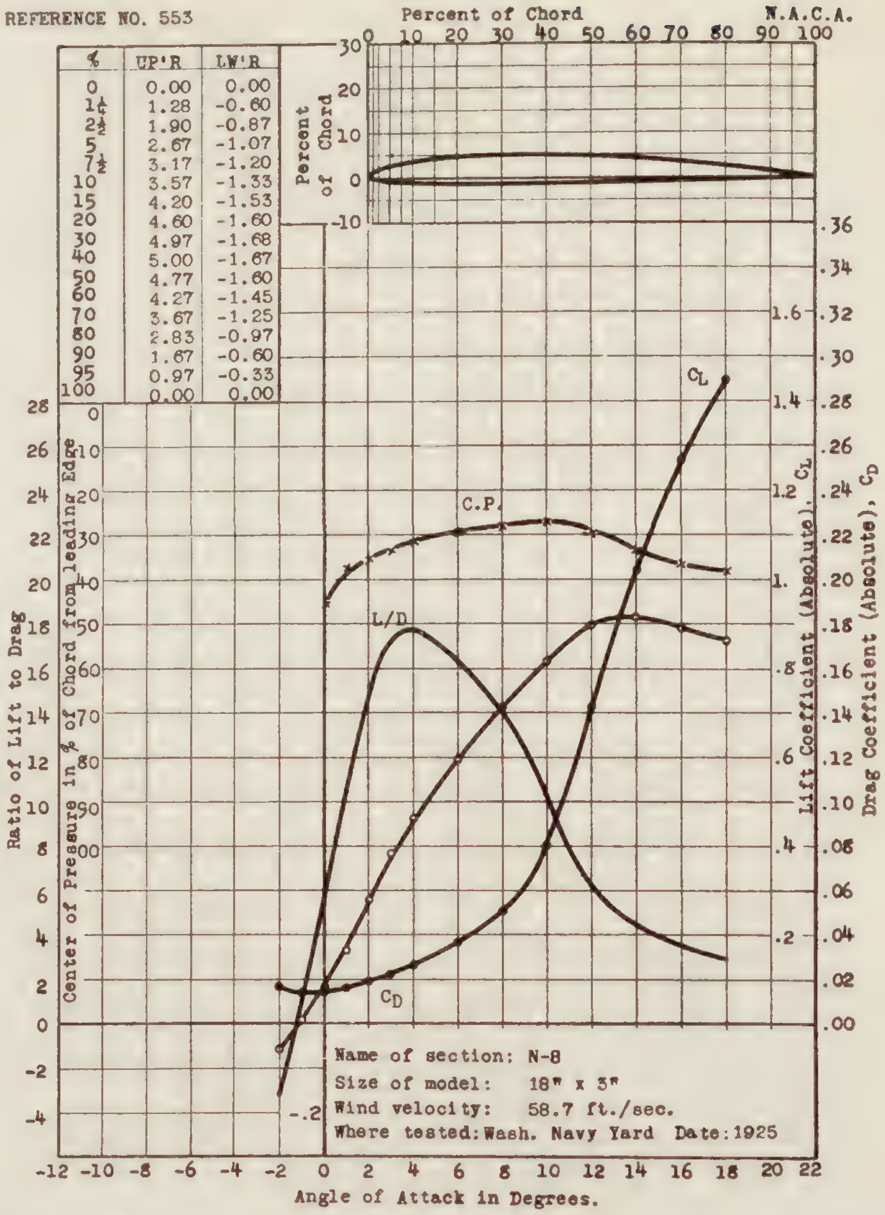
REFERENCE NO. 552



%	UP'R	LW'R
0	0.00	0.00
1¼	1.40	-0.48
2½	1.95	-0.65
5	2.77	-0.93
7½	3.30	-1.13
10	3.71	-1.27
15	4.30	-1.47
20	4.70	-1.57
30	4.98	-1.67
40	4.90	-1.63
50	4.55	-1.53
60	4.10	-1.33
70	3.33	-1.13
80	2.47	-0.80
90	1.33	-0.43
95	0.70	-0.20
100	0.00	0.00

Name of section: N-7
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1925

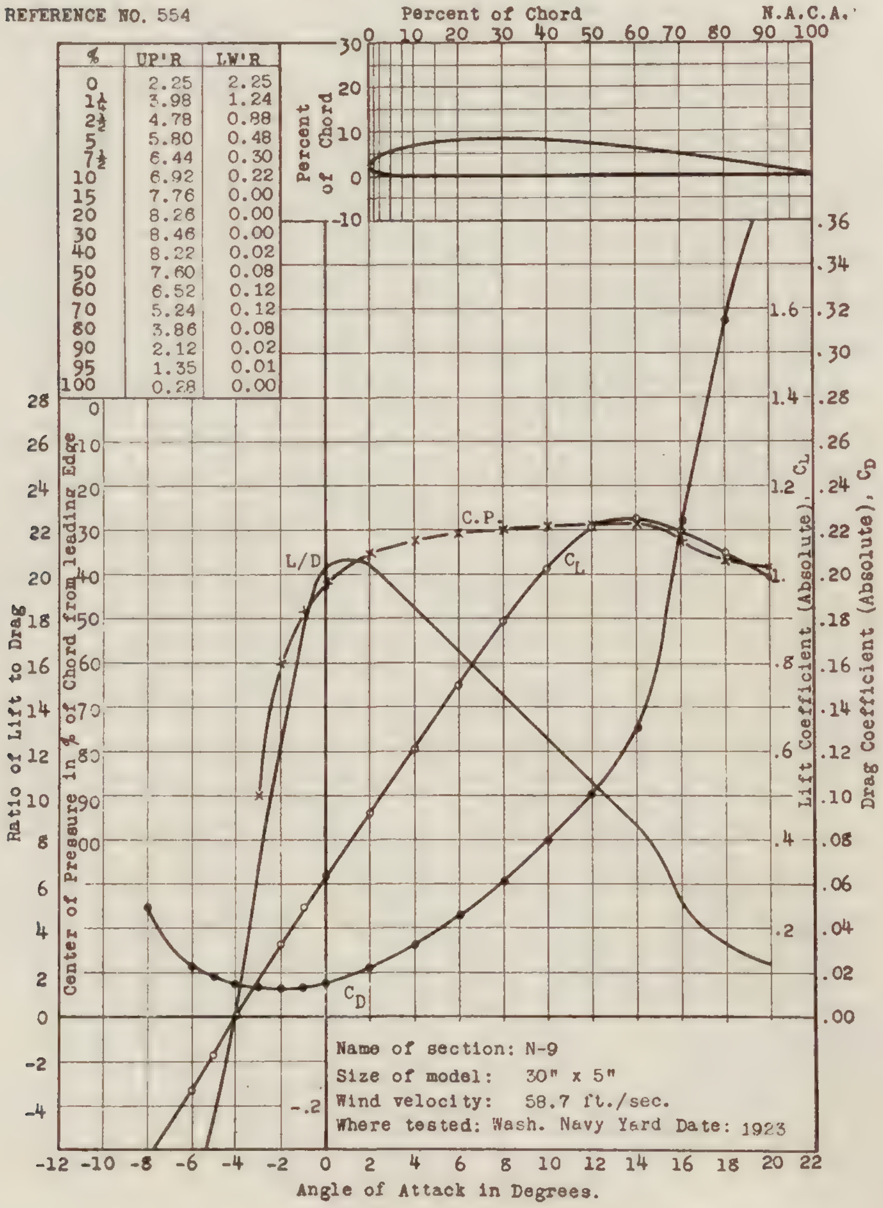
REFERENCE NO. 553



%	UP'R	LW'R
0	0.00	0.00
1¼	1.28	-0.60
2½	1.90	-0.87
5	2.67	-1.07
7½	3.17	-1.20
10	3.57	-1.33
15	4.20	-1.53
20	4.60	-1.60
30	4.97	-1.68
40	5.00	-1.67
50	4.77	-1.60
60	4.27	-1.45
70	3.67	-1.25
80	2.83	-0.97
90	1.67	-0.60
95	0.97	-0.33
100	0.00	0.00

Name of section: N-8
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1925

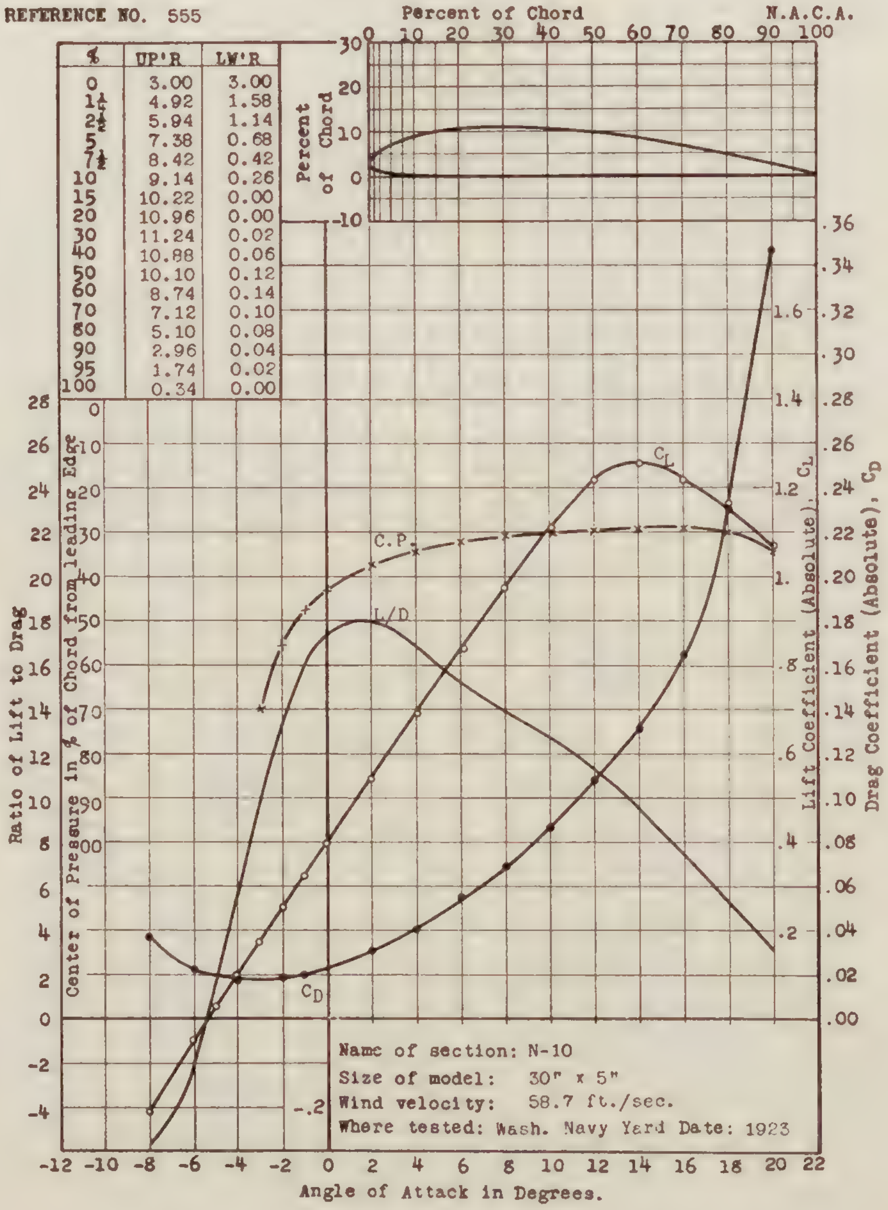
REFERENCE NO. 554



%	UP'R	LW'R
0	2.25	2.25
1¼	3.98	1.24
2½	4.78	0.88
5	5.80	0.48
7½	6.44	0.30
10	6.92	0.22
15	7.76	0.00
20	8.26	0.00
30	8.46	0.00
40	8.22	0.02
50	7.60	0.08
60	6.52	0.12
70	5.24	0.12
80	3.86	0.08
90	2.12	0.02
95	1.35	0.01
100	0.28	0.00

Name of section: N-9
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1923

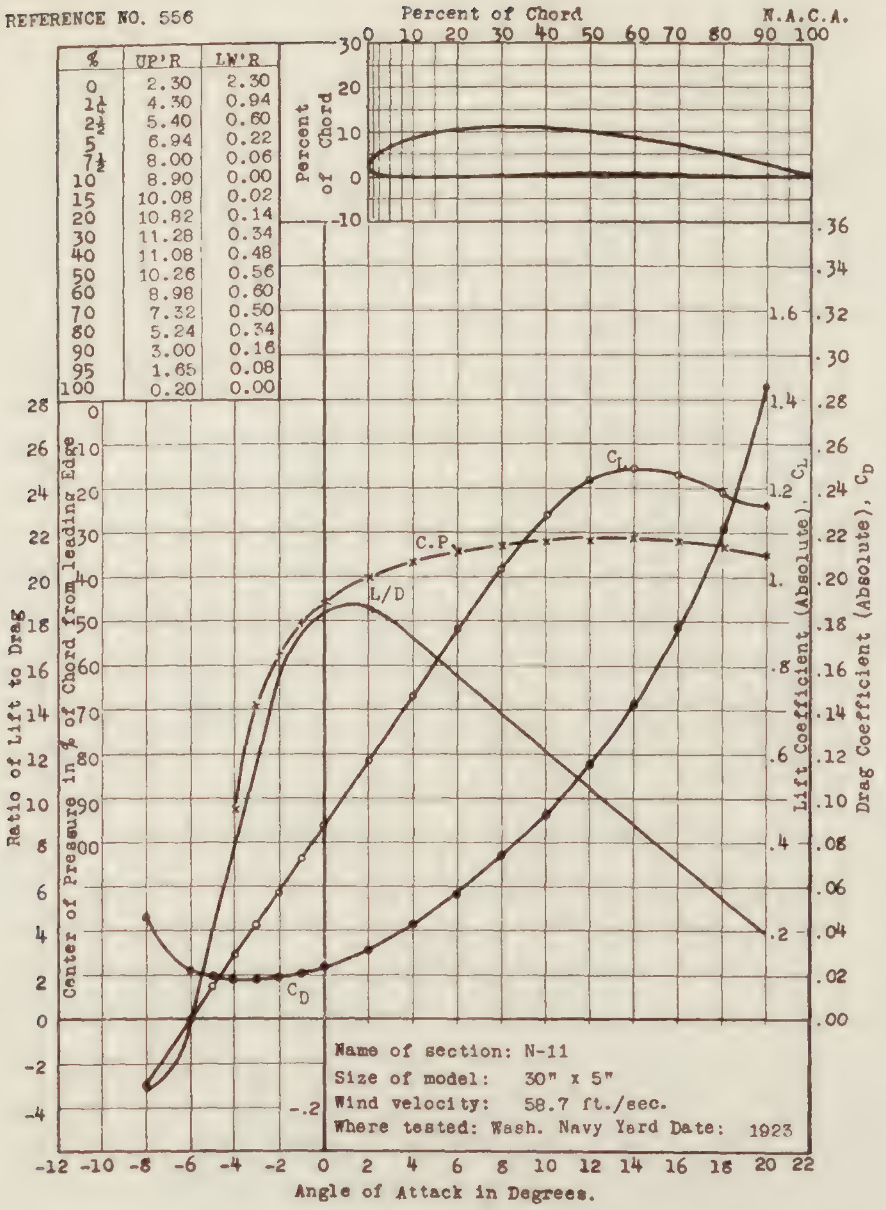
REFERENCE NO. 555



%	UP'R	LW'R
0	3.00	3.00
1¼	4.92	1.58
2½	5.94	1.14
5	7.38	0.68
7½	8.42	0.42
10	9.14	0.26
15	10.22	0.00
20	10.96	0.00
30	11.24	0.02
40	10.88	0.06
50	10.10	0.12
60	8.74	0.14
70	7.12	0.10
80	5.10	0.08
90	2.96	0.04
95	1.74	0.02
100	0.34	0.00

Name of section: N-10
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1923

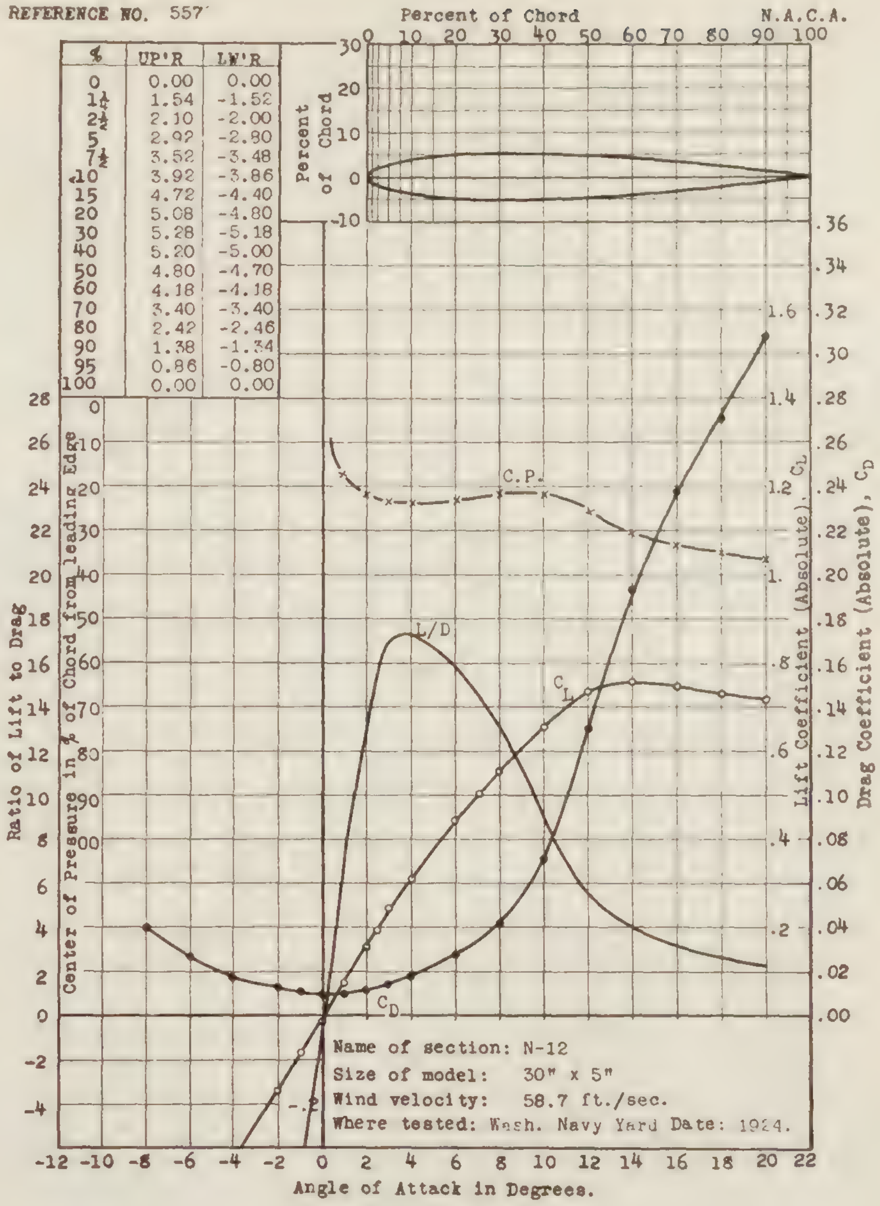
REFERENCE NO. 556



%	UP'R	LW'R
0	2.30	2.30
1¼	4.30	0.94
2½	5.40	0.60
5	6.94	0.22
7½	8.00	0.06
10	8.90	0.00
15	10.08	0.02
20	10.82	0.14
30	11.28	0.34
40	11.08	0.48
50	10.26	0.56
60	8.98	0.60
70	7.32	0.50
80	5.24	0.34
90	3.00	0.16
95	1.65	0.08
100	0.20	0.00

Name of section: N-11
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1923

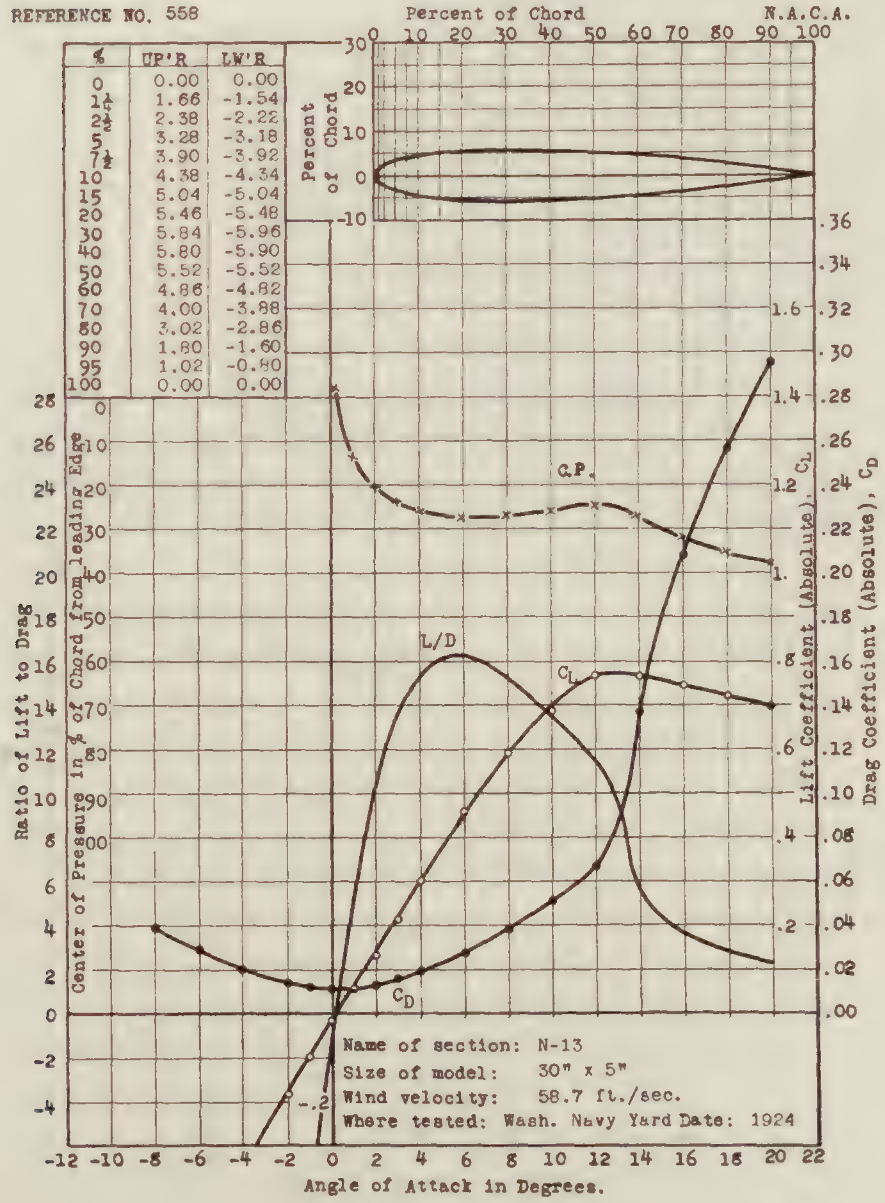
REFERENCE NO. 557



%	UP'R	LW'R
0	0.00	0.00
1¼	1.54	-1.52
2½	2.10	-2.00
5	2.92	-2.80
7½	3.52	-3.48
10	3.92	-3.86
15	4.72	-4.40
20	5.08	-4.80
30	5.28	-5.18
40	5.20	-5.00
50	4.80	-4.70
60	4.18	-4.18
70	3.40	-3.40
80	2.42	-2.46
90	1.38	-1.34
95	0.86	-0.80
100	0.00	0.00

Name of section: N-12
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1924.

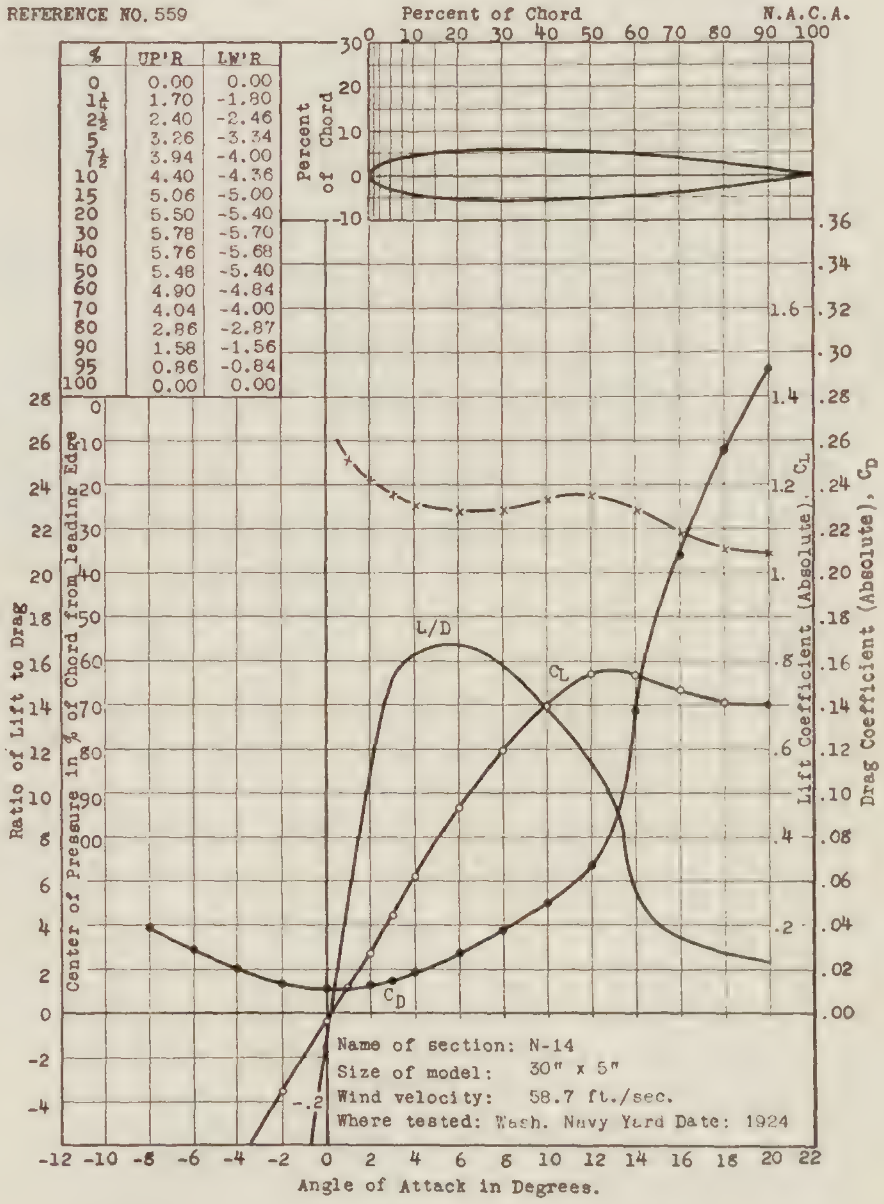
REFERENCE NO. 558



%	UP'R	LW'R
0	0.00	0.00
1¼	1.66	-1.54
2½	2.38	-2.22
5	3.28	-3.18
7½	3.90	-3.92
10	4.38	-4.34
15	5.04	-5.04
20	5.46	-5.48
30	5.84	-5.96
40	5.80	-5.90
50	5.52	-5.52
60	4.86	-4.82
70	4.00	-3.88
80	3.02	-2.86
90	1.80	-1.60
95	1.02	-0.80
100	0.00	0.00

Name of section: N-13
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1924

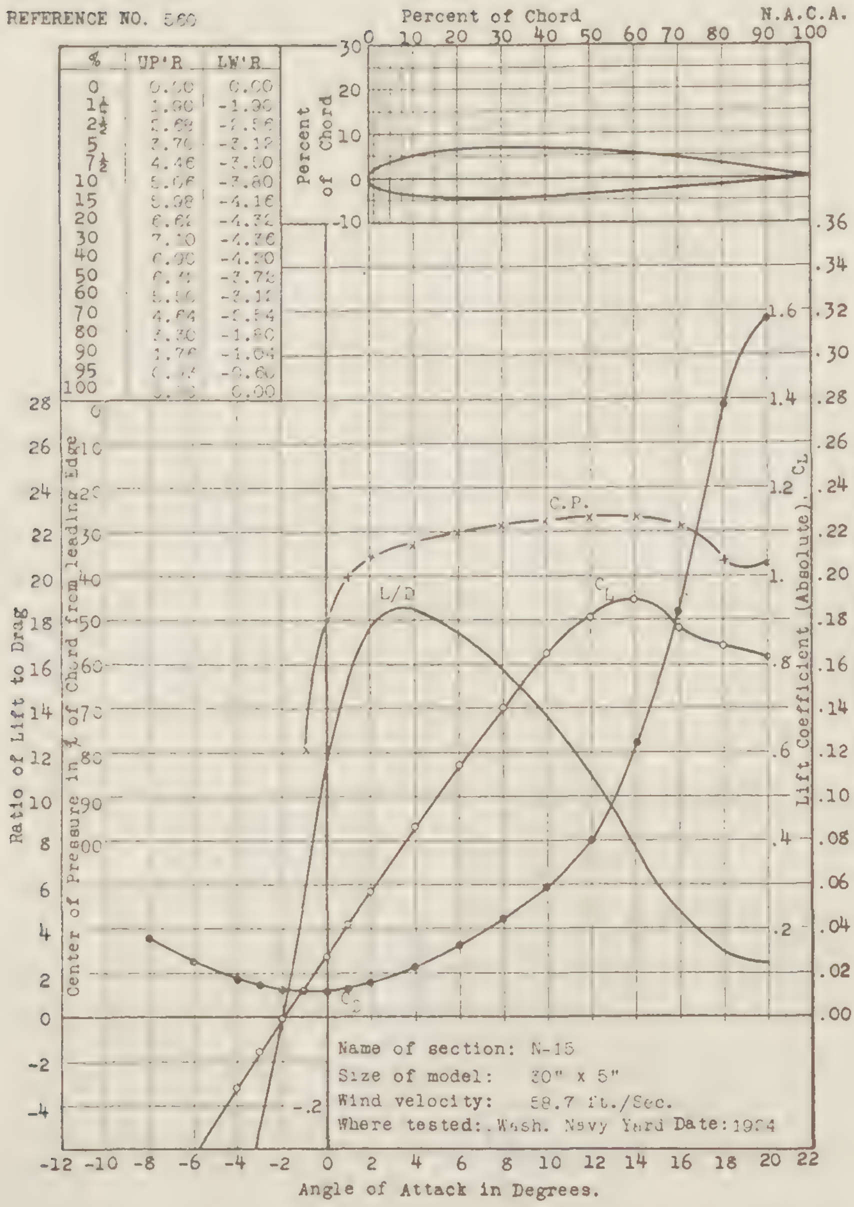
REFERENCE NO. 559



%	UP'R	LW'R
0	0.00	0.00
1¼	1.70	-1.80
2½	2.40	-2.46
5	3.26	-3.34
7½	3.94	-4.00
10	4.40	-4.36
15	5.06	-5.00
20	5.50	-5.40
30	5.78	-5.70
40	5.76	-5.68
50	5.48	-5.40
60	4.90	-4.84
70	4.04	-4.00
80	2.86	-2.87
90	1.58	-1.56
95	0.86	-0.84
100	0.00	0.00

Name of section: N-14
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1924

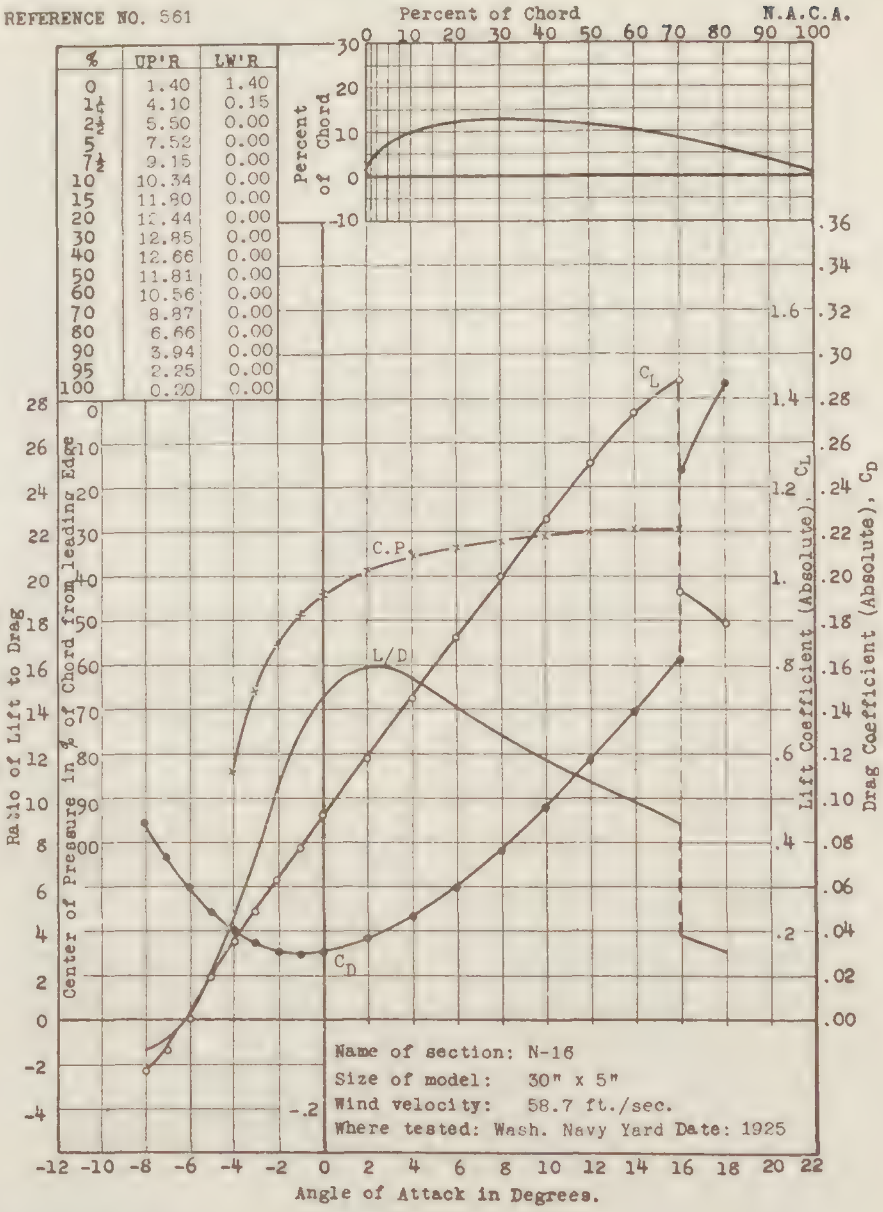
REFERENCE NO. 560



%	UP'R	LW'R
0	0.00	0.00
1¼	1.90	-1.30
2½	2.68	-2.56
5	3.76	-3.12
7½	4.46	-3.50
10	5.06	-3.80
15	5.98	-4.16
20	6.64	-4.32
30	7.10	-4.36
40	6.90	-4.30
50	[illegible]	-3.72
60	5.56	-3.12
70	4.64	-2.54
80	3.30	-1.80
90	1.76	-1.04
95	[illegible]	-0.60
100	[illegible]	0.00

Name of section: N-15
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1924

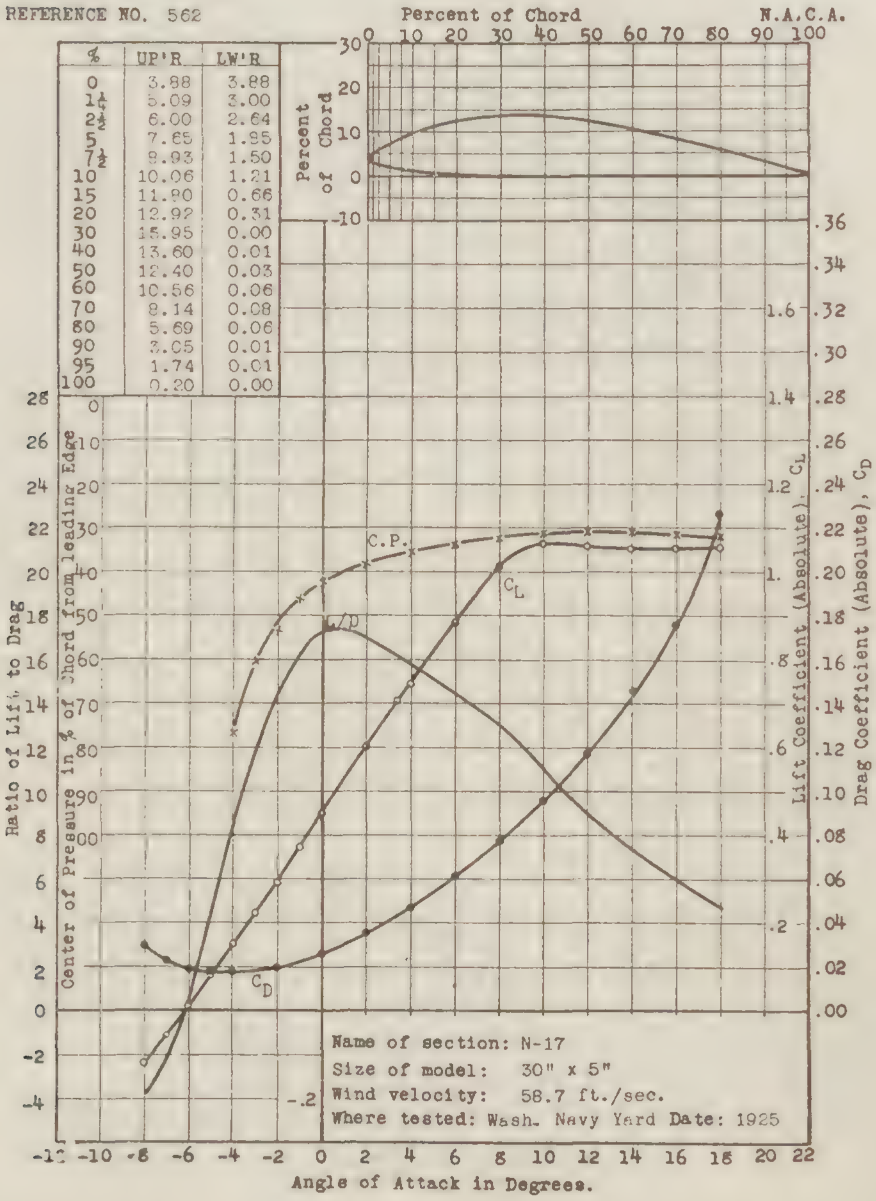
REFERENCE NO. 561



%	UP'R	LW'R
0	1.40	1.40
1¼	4.10	0.15
2½	5.50	0.00
5	7.52	0.00
7½	9.15	0.00
10	10.34	0.00
15	11.80	0.00
20	12.44	0.00
30	12.85	0.00
40	12.66	0.00
50	11.81	0.00
60	10.56	0.00
70	8.87	0.00
80	6.66	0.00
90	3.94	0.00
95	2.25	0.00
100	0.20	0.00

Name of section: N-16
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1925

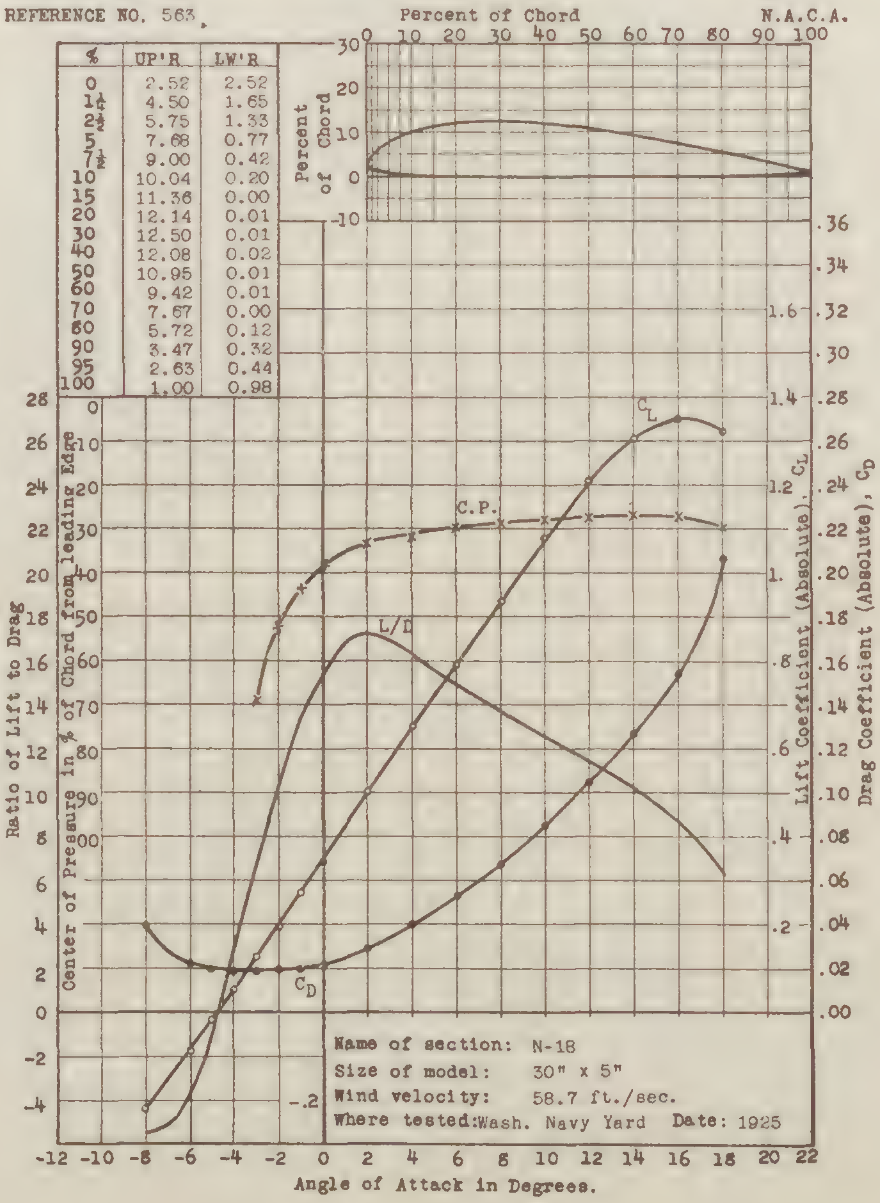
REFERENCE NO. 562



%	UP'R	LW'R
0	3.88	3.88
1¼	5.09	3.00
2½	6.00	2.64
5	7.65	1.95
7½	8.93	1.50
10	10.06	1.21
15	11.80	0.66
20	12.92	0.31
30	13.95	0.00
40	13.60	0.01
50	12.40	0.03
60	10.56	0.06
70	8.14	0.08
80	5.69	0.06
90	3.05	0.01
95	1.74	0.01
100	0.20	0.00

Name of section: N-17
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1925

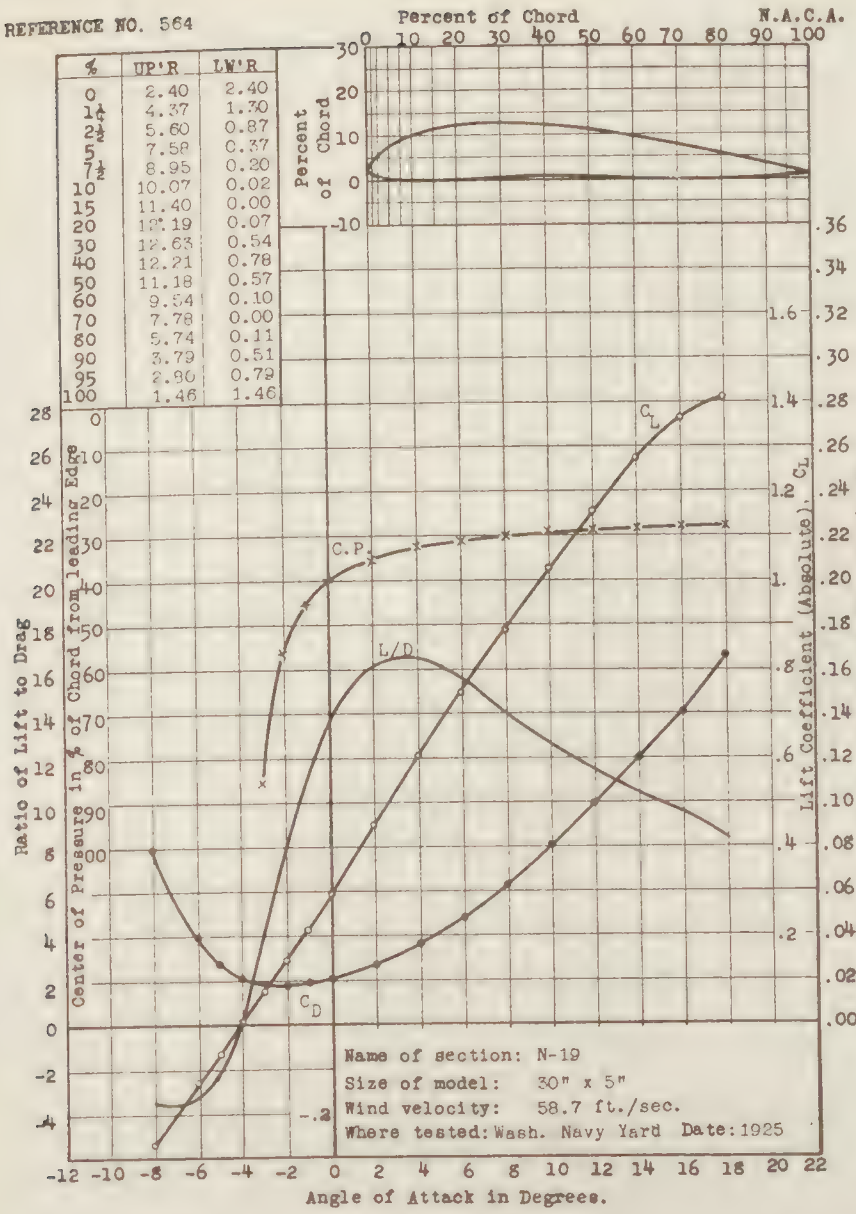
REFERENCE NO. 563



%	UP'R	LW'R
0	2.52	2.52
1¼	4.50	1.65
2½	5.75	1.33
5	7.68	0.77
7½	9.00	0.42
10	10.04	0.20
15	11.36	0.00
20	12.14	0.01
30	12.50	0.01
40	12.08	0.02
50	10.95	0.01
60	9.42	0.01
70	7.67	0.00
80	5.72	0.12
90	3.47	0.32
95	2.63	0.44
100	1.00	0.98

Name of section: N-18
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1925

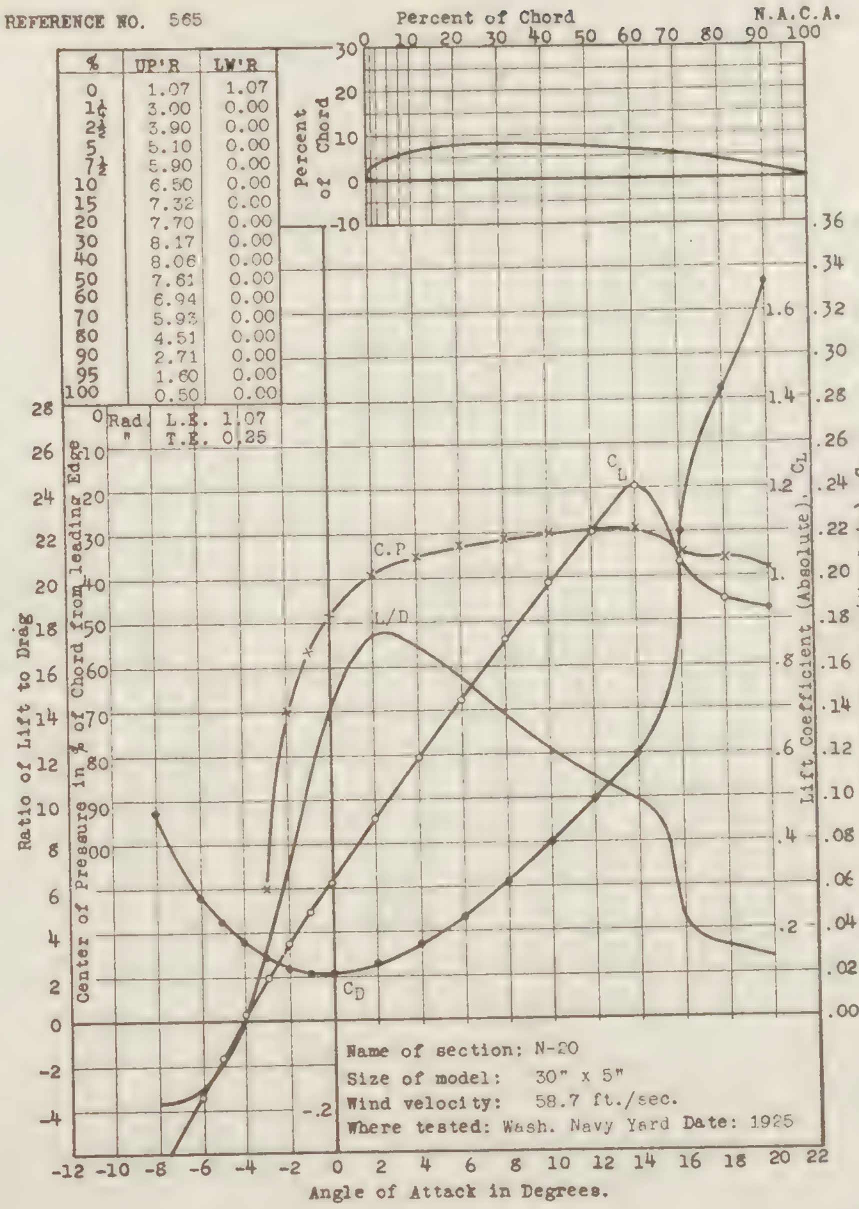
REFERENCE NO. 564



%	UP'R	LW'R
0	2.40	2.40
1¼	4.37	1.30
2½	5.60	0.87
5	7.58	0.37
7½	8.95	0.20
10	10.07	0.02
15	11.40	0.00
20	12.19	0.07
30	12.63	0.54
40	12.21	0.78
50	11.18	0.57
60	9.54	0.10
70	7.78	0.00
80	5.74	0.11
90	3.79	0.51
95	2.80	0.79
100	1.46	1.46

Name of section: N-19
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1925

REFERENCE NO. 565

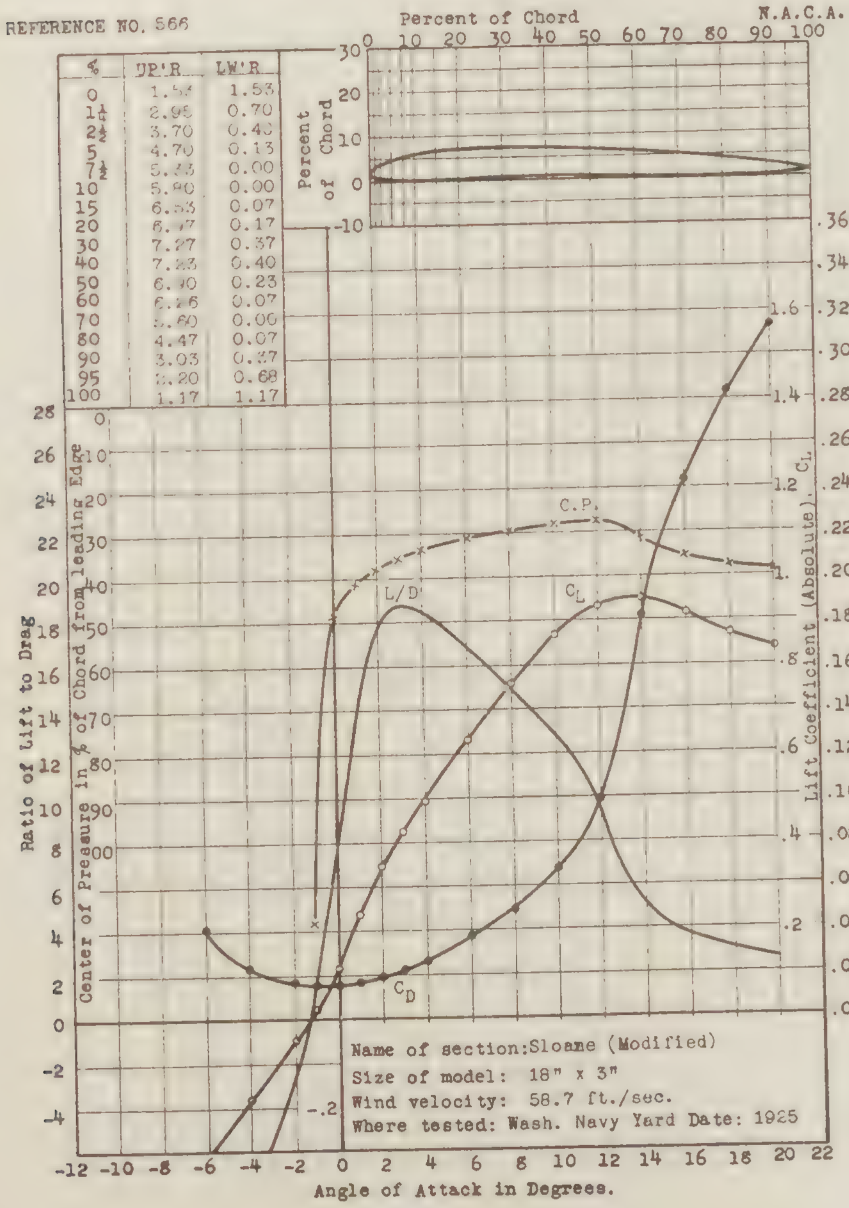


%	UP'R	LW'R
0	1.07	1.07
1¼	3.00	0.00
2½	3.90	0.00
5	5.10	0.00
7½	5.90	0.00
10	6.50	0.00
15	7.32	0.00
20	7.70	0.00
30	8.17	0.00
40	8.06	0.00
50	7.61	0.00
60	6.94	0.00
70	5.93	0.00
80	4.51	0.00
90	2.71	0.00
95	1.60	0.00
100	0.50	0.00

Rad. L.E. 1.07
" T.E. 0.25

Name of section: N-20
Size of model: 30" x 5"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1925

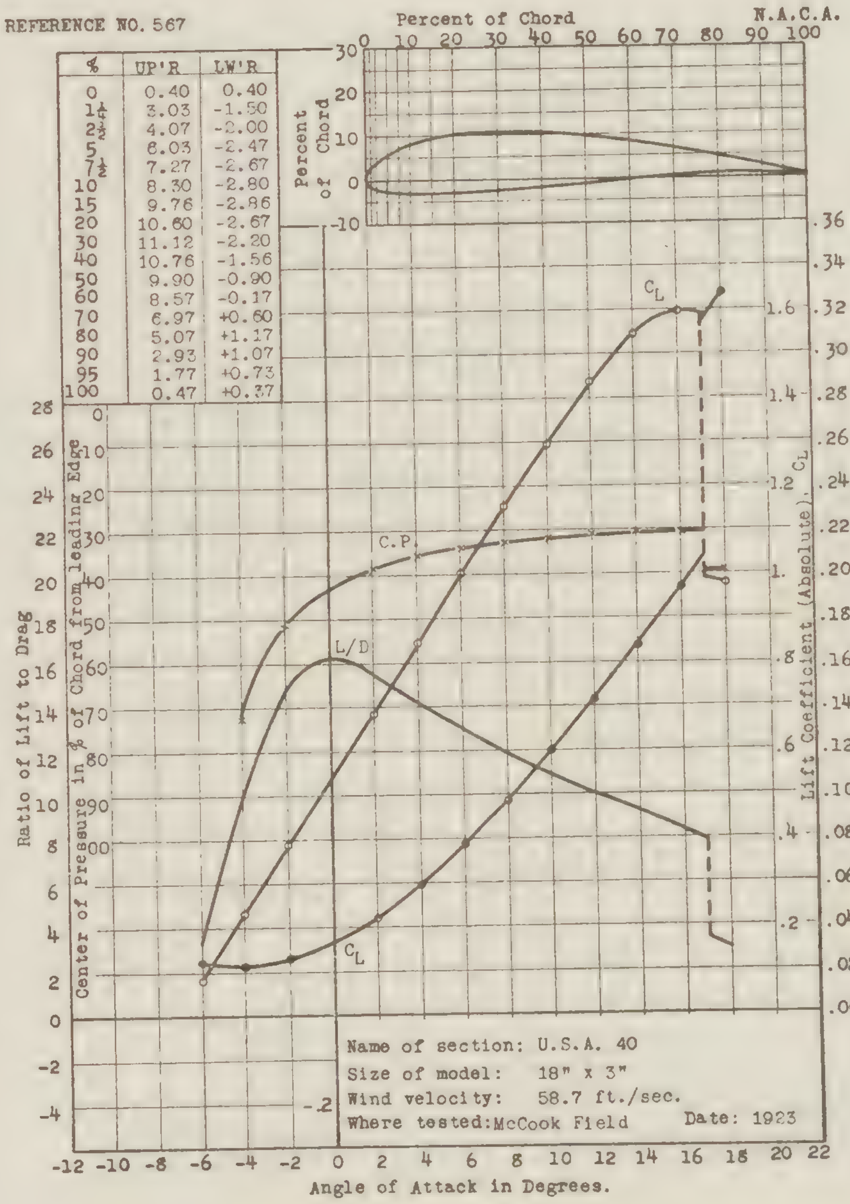
REFERENCE NO. 566



%	UP'R	LW'R
0	1.53	1.53
1¼	2.95	0.70
2½	3.70	0.40
5	4.70	0.13
7½	5.33	0.00
10	5.80	0.00
15	6.53	0.07
20	6.97	0.17
30	7.27	0.37
40	7.23	0.40
50	6.90	0.23
60	6.26	0.07
70	5.60	0.00
80	4.47	0.07
90	3.03	0.37
95	2.20	0.68
100	1.17	1.17

Name of section: Sloane (Modified)
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: Wash. Navy Yard Date: 1925

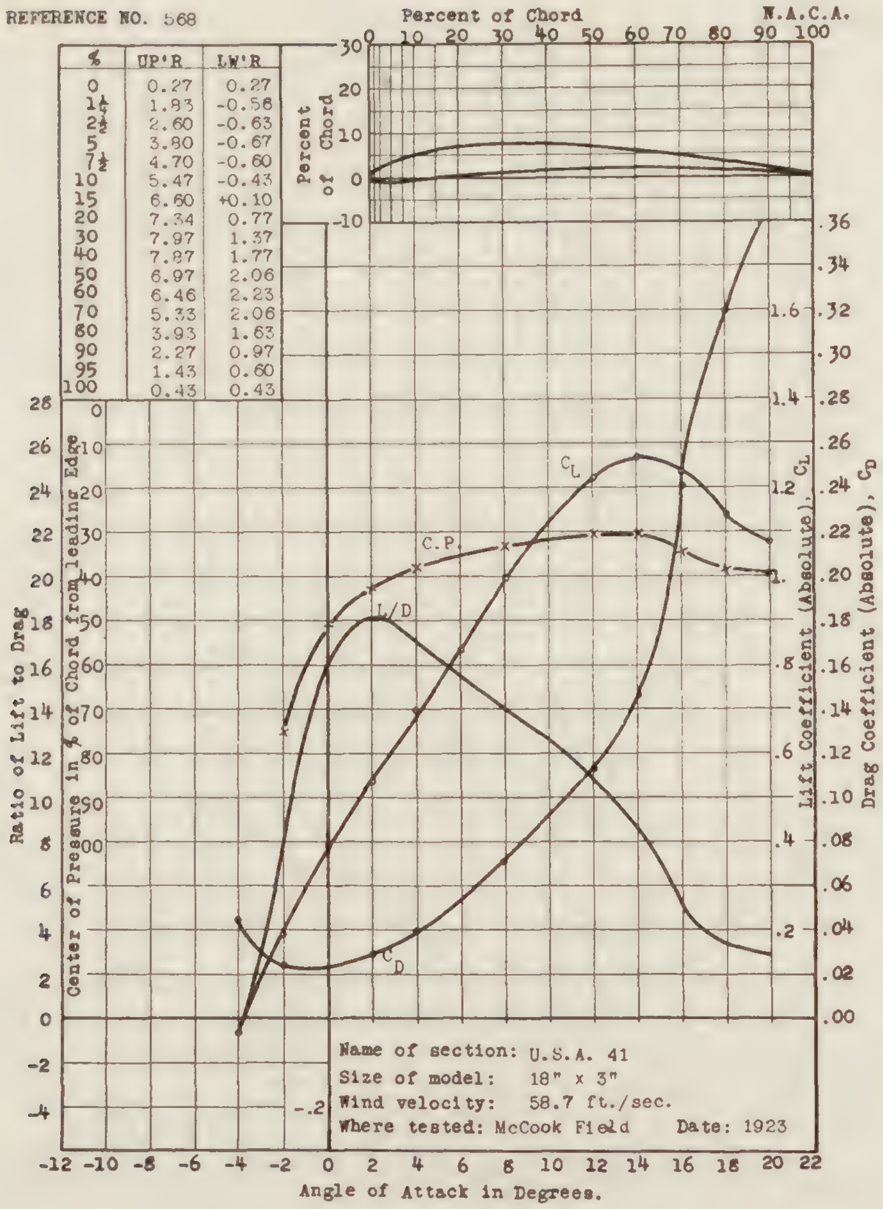
REFERENCE NO. 567



%	UP'R	LW'R
0	0.40	0.40
1¼	3.03	-1.50
2½	4.07	-2.00
5	6.03	-2.47
7½	7.27	-2.67
10	8.30	-2.80
15	9.76	-2.86
20	10.60	-2.67
30	11.12	-2.20
40	10.76	-1.56
50	9.90	-0.90
60	8.57	-0.17
70	6.97	+0.60
80	5.07	+1.17
90	2.93	+1.07
95	1.77	+0.73
100	0.47	+0.37

Name of section: U.S.A. 40
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: McCook Field Date: 1923

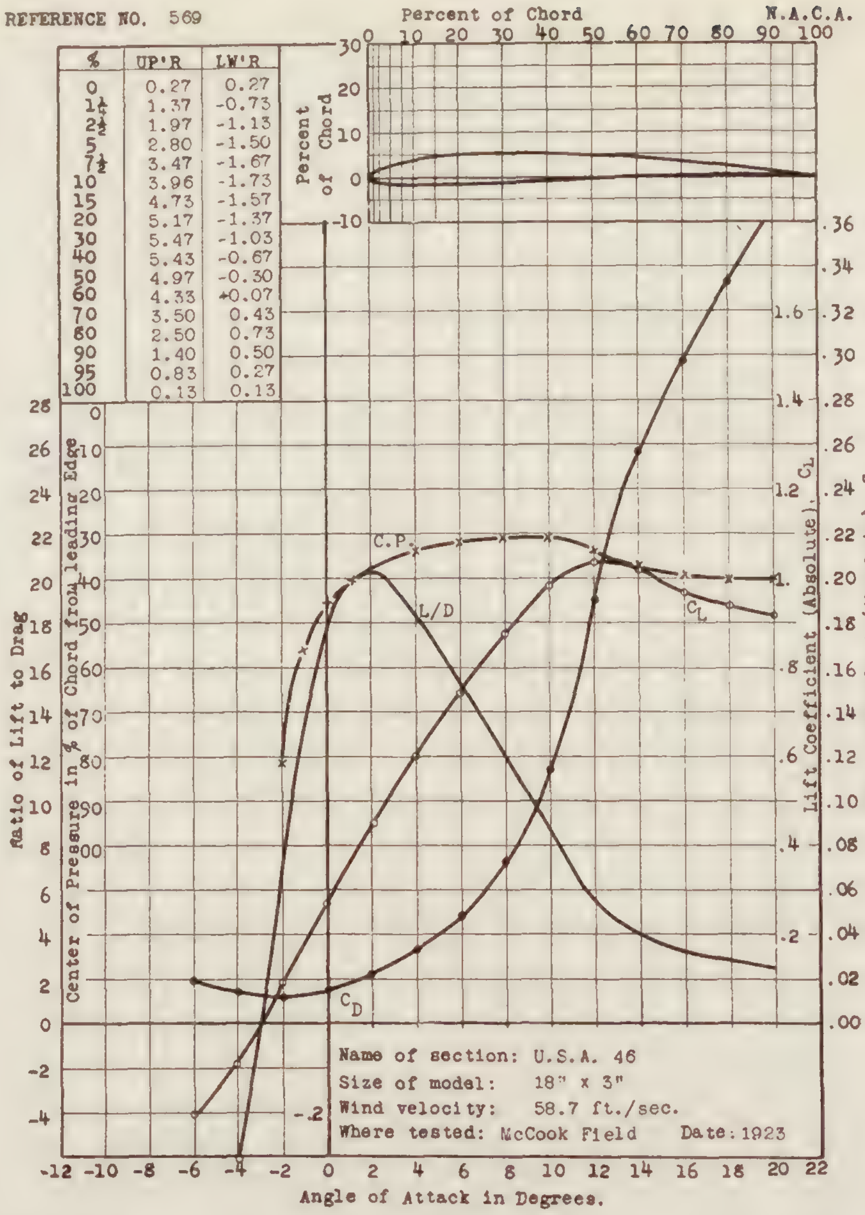
REFERENCE NO. 568



%	UP'R	LW'R
0	0.27	0.27
1¼	1.83	-0.58
2½	2.60	-0.63
5	3.80	-0.67
7½	4.70	-0.60
10	5.47	-0.43
15	6.60	+0.10
20	7.34	0.77
30	7.97	1.37
40	7.87	1.77
50	6.97	2.06
60	6.46	2.23
70	5.33	2.06
80	3.93	1.63
90	2.27	0.97
95	1.43	0.60
100	0.43	0.43

Name of section: U.S.A. 41
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: McCook Field Date: 1923

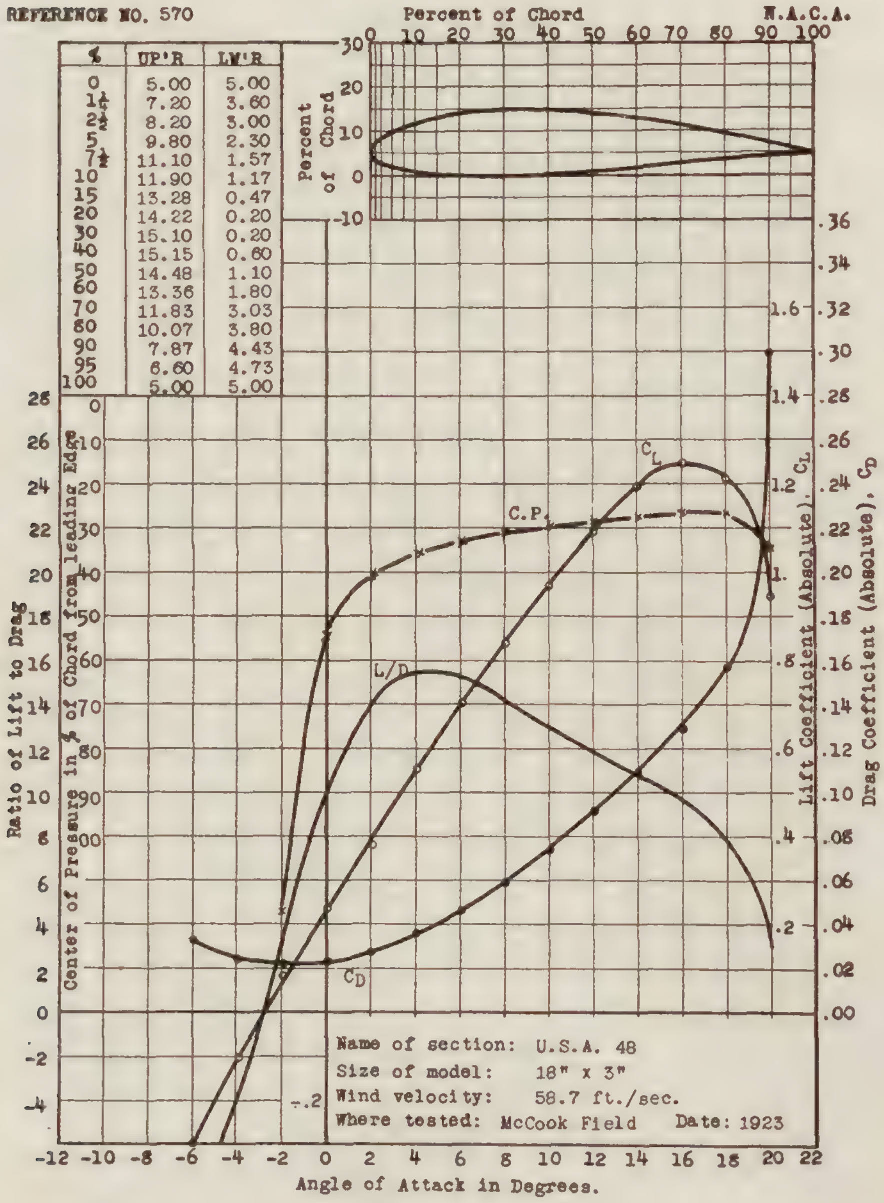
REFERENCE NO. 569



%	UP'R	LW'R
0	0.27	0.27
1¼	1.37	-0.73
2½	1.97	-1.13
5	2.80	-1.50
7½	3.47	-1.67
10	3.96	-1.73
15	4.73	-1.57
20	5.17	-1.37
30	5.47	-1.03
40	5.43	-0.67
50	4.97	-0.30
60	4.33	+0.07
70	3.50	0.43
80	2.50	0.73
90	1.40	0.50
95	0.83	0.27
100	0.13	0.13

Name of section: U.S.A. 46
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: McCook Field Date: 1923

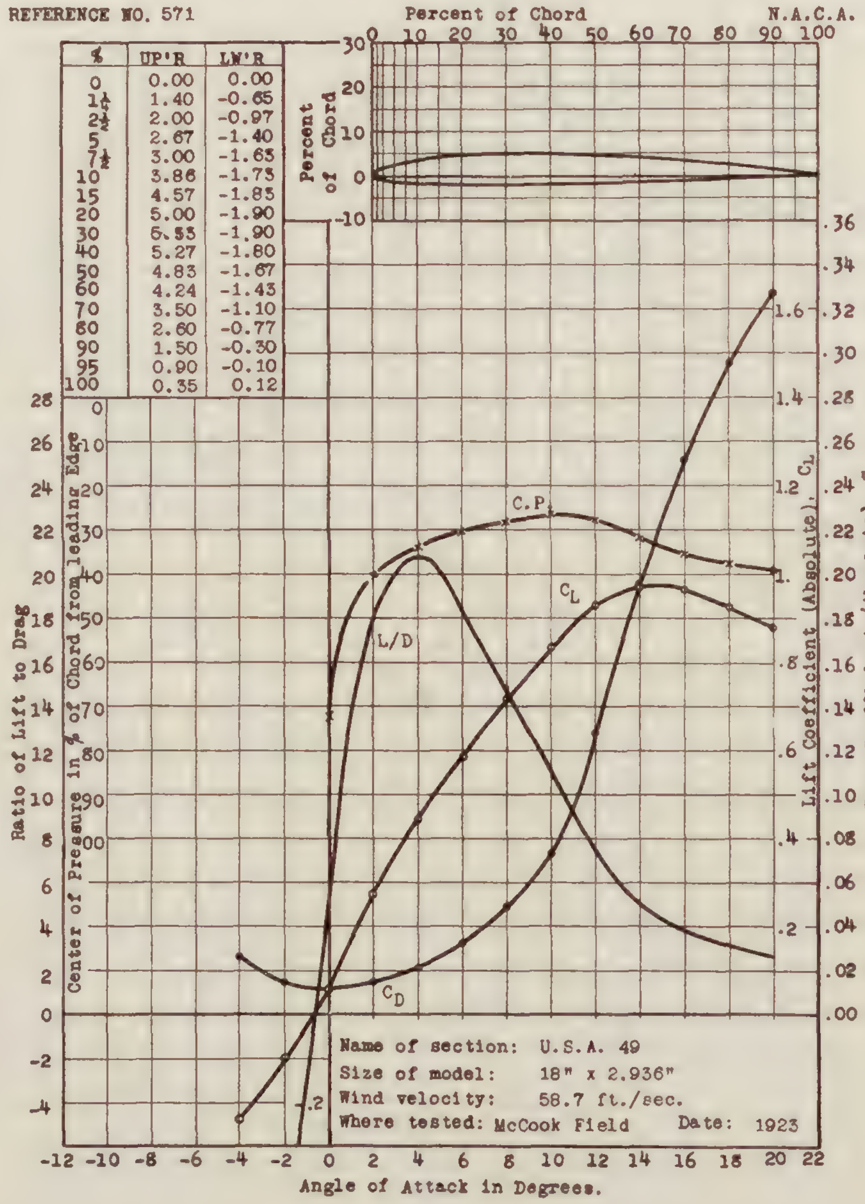
REFERENCE NO. 570



%	UP'R	LW'R
0	5.00	5.00
1¼	7.20	3.60
2½	8.20	3.00
5	9.80	2.30
7½	11.10	1.57
10	11.90	1.17
15	13.28	0.47
20	14.22	0.20
30	15.10	0.20
40	15.15	0.60
50	14.48	1.10
60	13.36	1.80
70	11.83	3.03
80	10.07	3.80
90	7.87	4.43
95	6.60	4.73
100	5.00	5.00

Name of section: U.S.A. 48
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: McCook Field Date: 1923

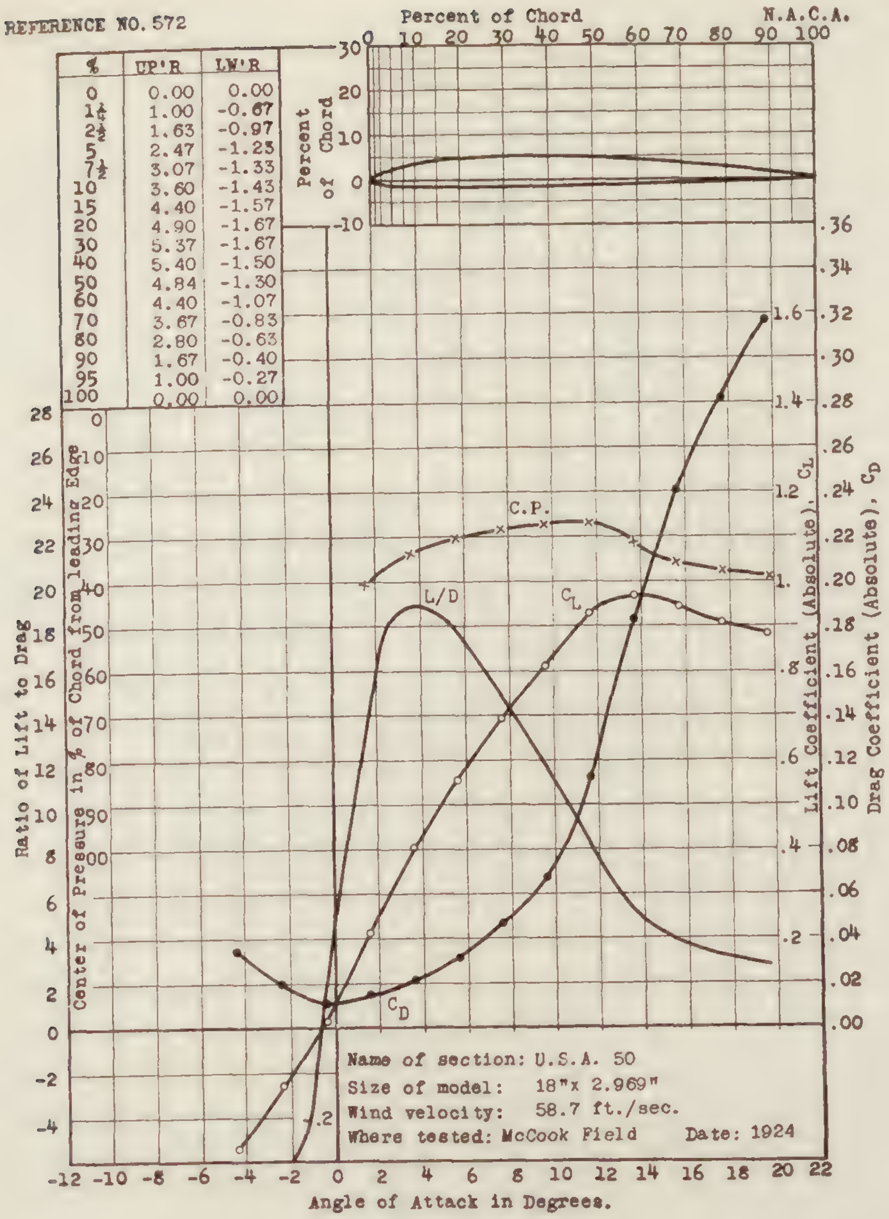
REFERENCE NO. 571



%	UP'R	LW'R
0	0.00	0.00
1¼	1.40	-0.65
2½	2.00	-0.97
5	2.67	-1.40
7½	3.00	-1.63
10	3.86	-1.73
15	4.57	-1.83
20	5.00	-1.90
30	5.33	-1.90
40	5.27	-1.80
50	4.83	-1.67
60	4.24	-1.43
70	3.50	-1.10
80	2.60	-0.77
90	1.50	-0.30
95	0.90	-0.10
100	0.35	0.12

Name of section: U.S.A. 49
Size of model: 18" x 2.936"
Wind velocity: 58.7 ft./sec.
Where tested: McCook Field Date: 1923

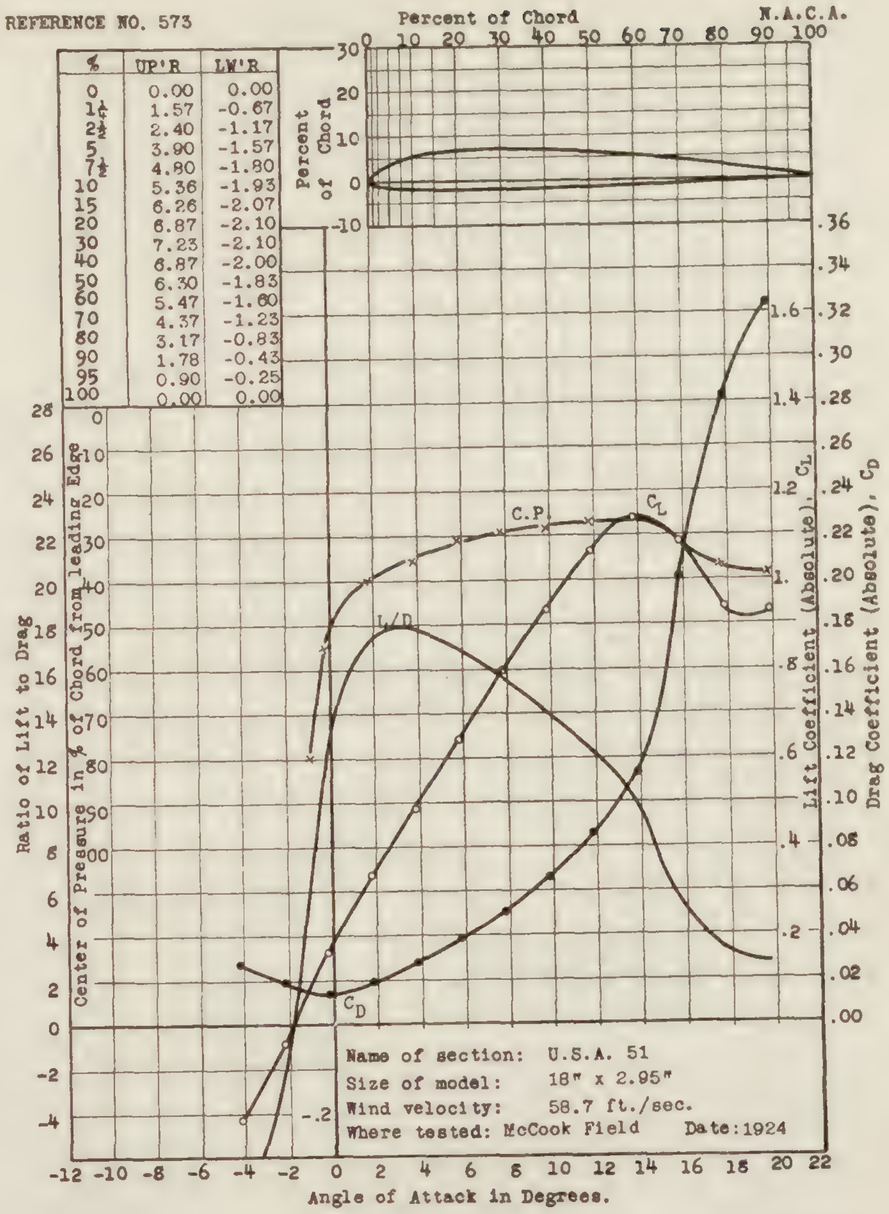
REFERENCE NO. 572



%	UP'R	LW'R
0	0.00	0.00
1¼	1.00	-0.67
2½	1.63	-0.97
5	2.47	-1.23
7½	3.07	-1.33
10	3.60	-1.43
15	4.40	-1.57
20	4.90	-1.67
30	5.37	-1.67
40	5.40	-1.50
50	4.84	-1.30
60	4.40	-1.07
70	3.67	-0.83
80	2.80	-0.63
90	1.67	-0.40
95	1.00	-0.27
100	0.00	0.00

Name of section: U.S.A. 50
Size of model: 18" x 2.969"
Wind velocity: 58.7 ft./sec.
Where tested: McCook Field Date: 1924

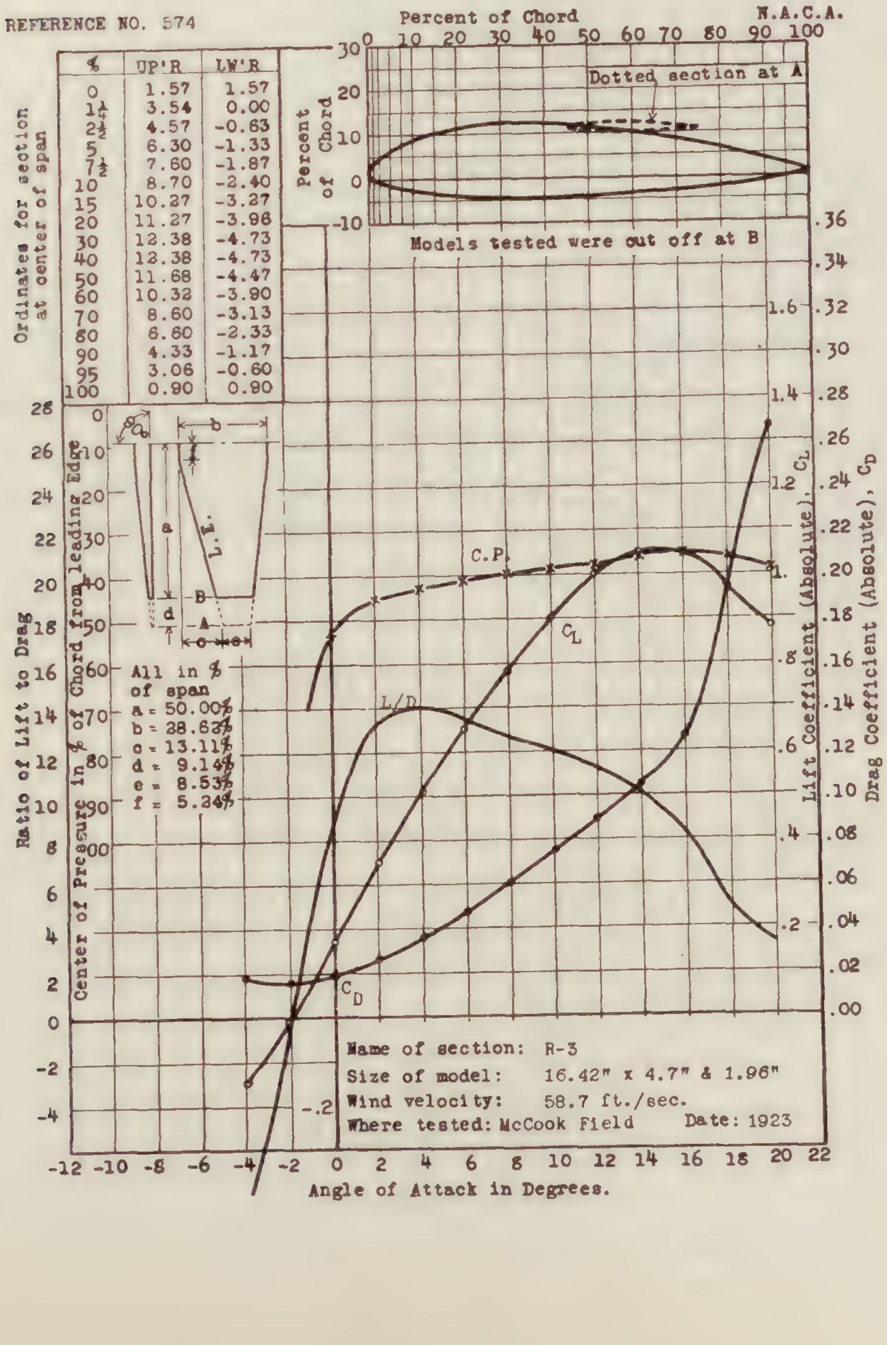
REFERENCE NO. 573



%	UP'R	LW'R
0	0.00	0.00
1¼	1.57	-0.67
2½	2.40	-1.17
5	3.90	-1.57
7½	4.80	-1.80
10	5.36	-1.93
15	6.26	-2.07
20	6.87	-2.10
30	7.23	-2.10
40	6.87	-2.00
50	6.30	-1.83
60	5.47	-1.60
70	4.37	-1.23
80	3.17	-0.83
90	1.78	-0.43
95	0.90	-0.25
100	0.00	0.00

Name of section: U.S.A. 51
Size of model: 18" x 2.95"
Wind velocity: 58.7 ft./sec.
Where tested: McCook Field Date: 1924

REFERENCE NO. 574

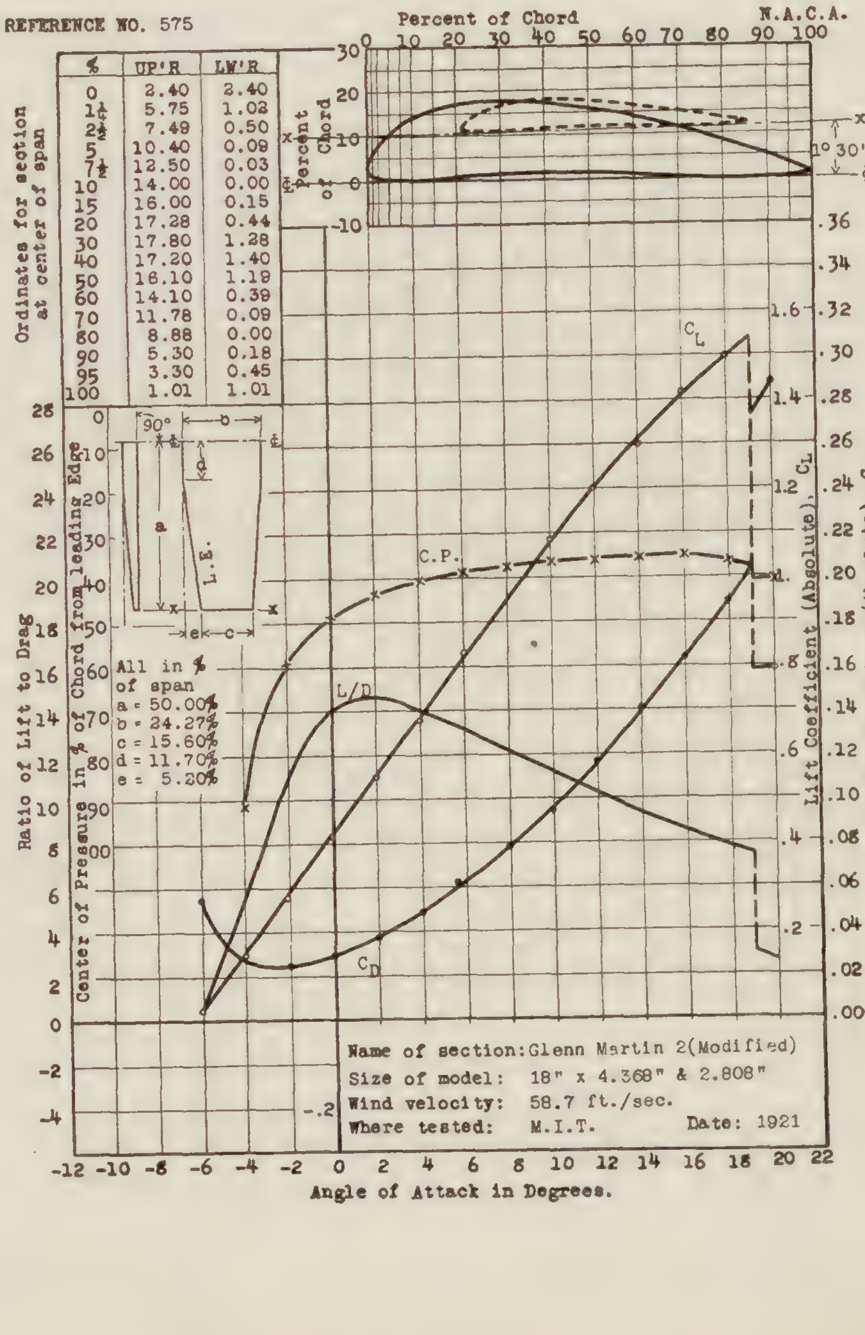


%	UP'R	LW'R
0	1.57	1.57
1¼	3.54	0.00
2½	4.57	-0.63
5	6.30	-1.33
7½	7.60	-1.87
10	8.70	-2.40
15	10.27	-3.27
20	11.27	-3.98
30	12.38	-4.73
40	12.38	-4.73
50	11.68	-4.47
60	10.32	-3.90
70	8.60	-3.13
80	6.60	-2.33
90	4.33	-1.17
95	3.06	-0.60
100	0.90	0.90

All in %
of span
a = 50.00%
b = 28.63%
c = 13.11%
d = 9.14%
e = 8.53%
f = 5.34%

Name of section: R-3
Size of model: 16.42" x 4.7" & 1.96"
Wind velocity: 58.7 ft./sec.
Where tested: McCook Field Date: 1923

REFERENCE NO. 575

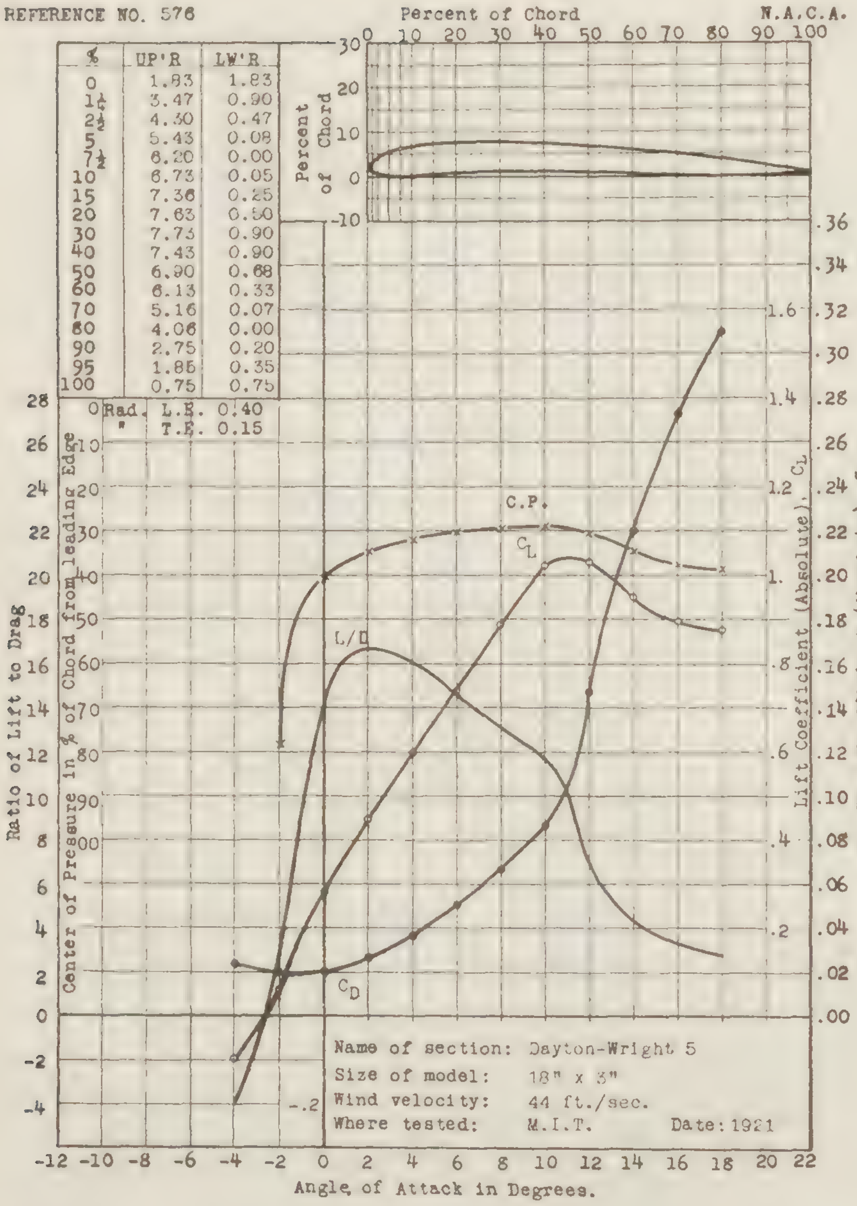


%	UP'R	LW'R
0	2.40	2.40
1¼	5.75	1.02
2½	7.49	0.50
5	10.40	0.09
7½	12.50	0.03
10	14.00	0.00
15	16.00	0.15
20	17.28	0.44
30	17.80	1.28
40	17.20	1.40
50	16.10	1.19
60	14.10	0.39
70	11.78	0.09
80	8.88	0.00
90	5.30	0.18
95	3.30	0.45
100	1.01	1.01

All in %
of span
a = 50.00%
b = 24.27%
c = 15.60%
d = 11.70%
e = 5.20%

Name of section: Glenn Martin 2 (Modified)
Size of model: 18" x 4.368" & 2.808"
Wind velocity: 58.7 ft./sec.
Where tested: M.I.T. Date: 1921

REFERENCE NO. 576

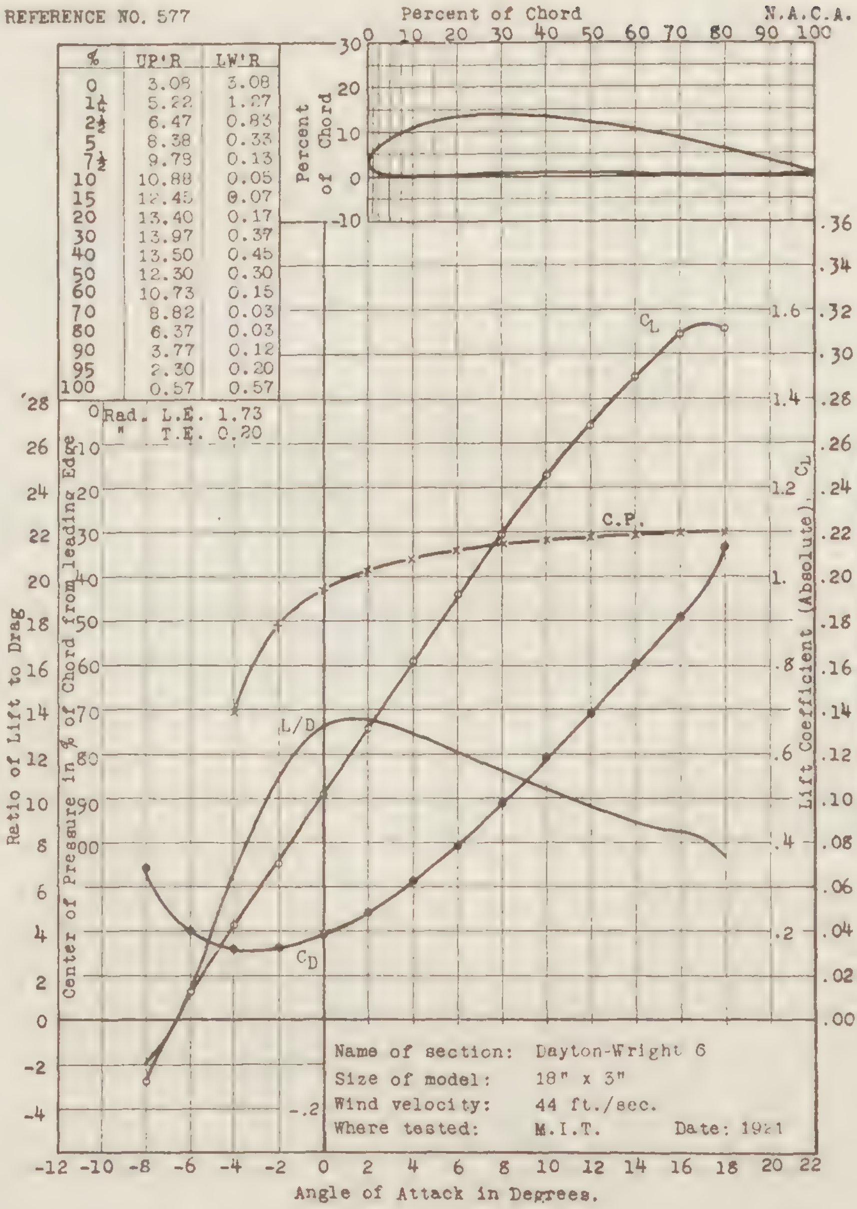


%	UP'R	LW'R
0	1.83	1.83
1¼	3.47	0.90
2½	4.30	0.47
5	5.43	0.08
7½	6.20	0.00
10	6.73	0.05
15	7.36	0.25
20	7.63	0.50
30	7.73	0.90
40	7.43	0.90
50	6.90	0.68
60	6.13	0.33
70	5.16	0.07
80	4.06	0.00
90	2.75	0.20
95	1.86	0.35
100	0.75	0.75

Rad. L.E. 0.40
" T.E. 0.15

Name of section: Dayton-Wright 5
Size of model: 18" x 3"
Wind velocity: 44 ft./sec.
Where tested: M.I.T. Date: 1921

REFERENCE NO. 577

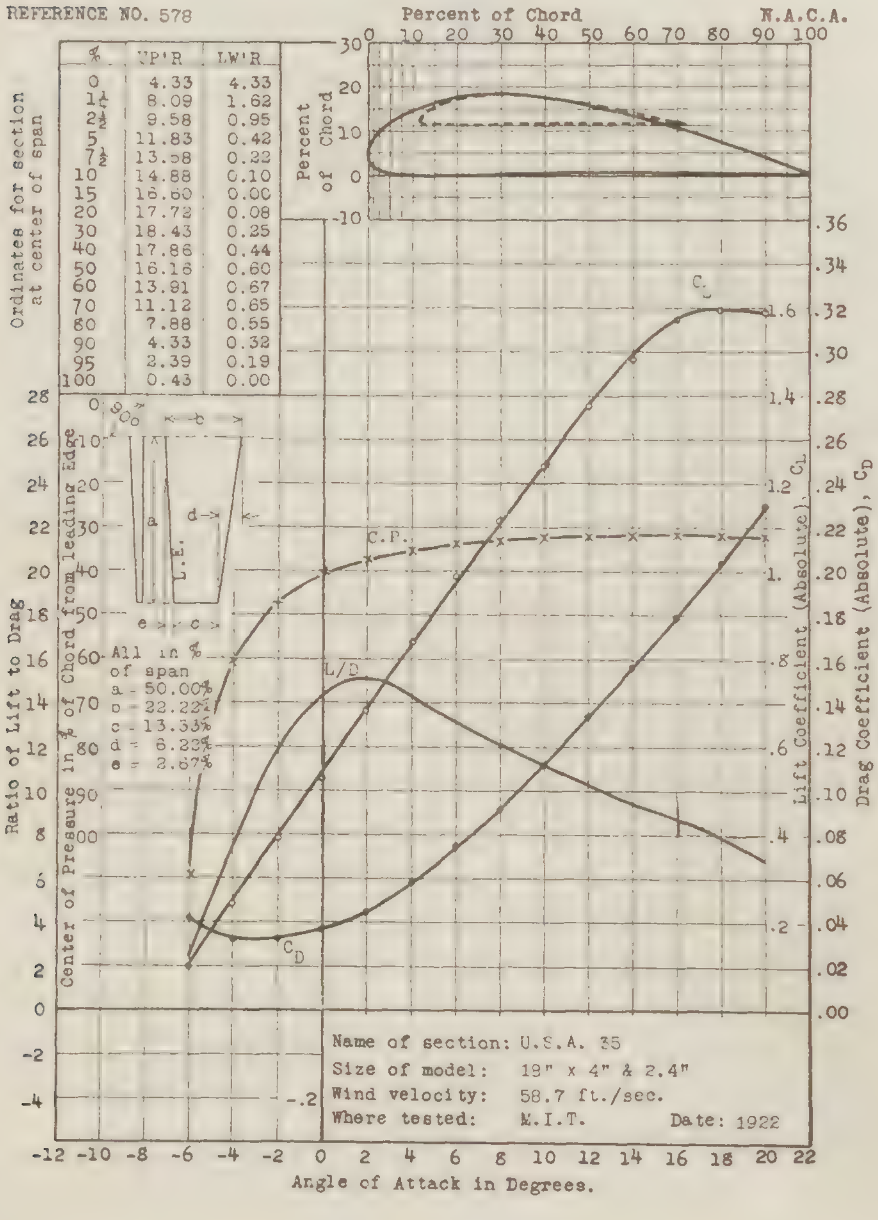


%	UP'R	LW'R
0	3.08	3.08
1¼	5.22	1.27
2½	6.47	0.83
5	8.38	0.33
7½	9.78	0.13
10	10.88	0.05
15	12.45	0.07
20	13.40	0.17
30	13.97	0.37
40	13.50	0.45
50	12.30	0.30
60	10.73	0.15
70	8.82	0.03
80	6.37	0.03
90	3.77	0.12
95	2.30	0.20
100	0.57	0.57

Rad. L.E. 1.73
" T.E. 0.20

Name of section: Dayton-Wright 6
Size of model: 18" x 3"
Wind velocity: 44 ft./sec.
Where tested: M.I.T. Date: 1921

REFERENCE NO. 578



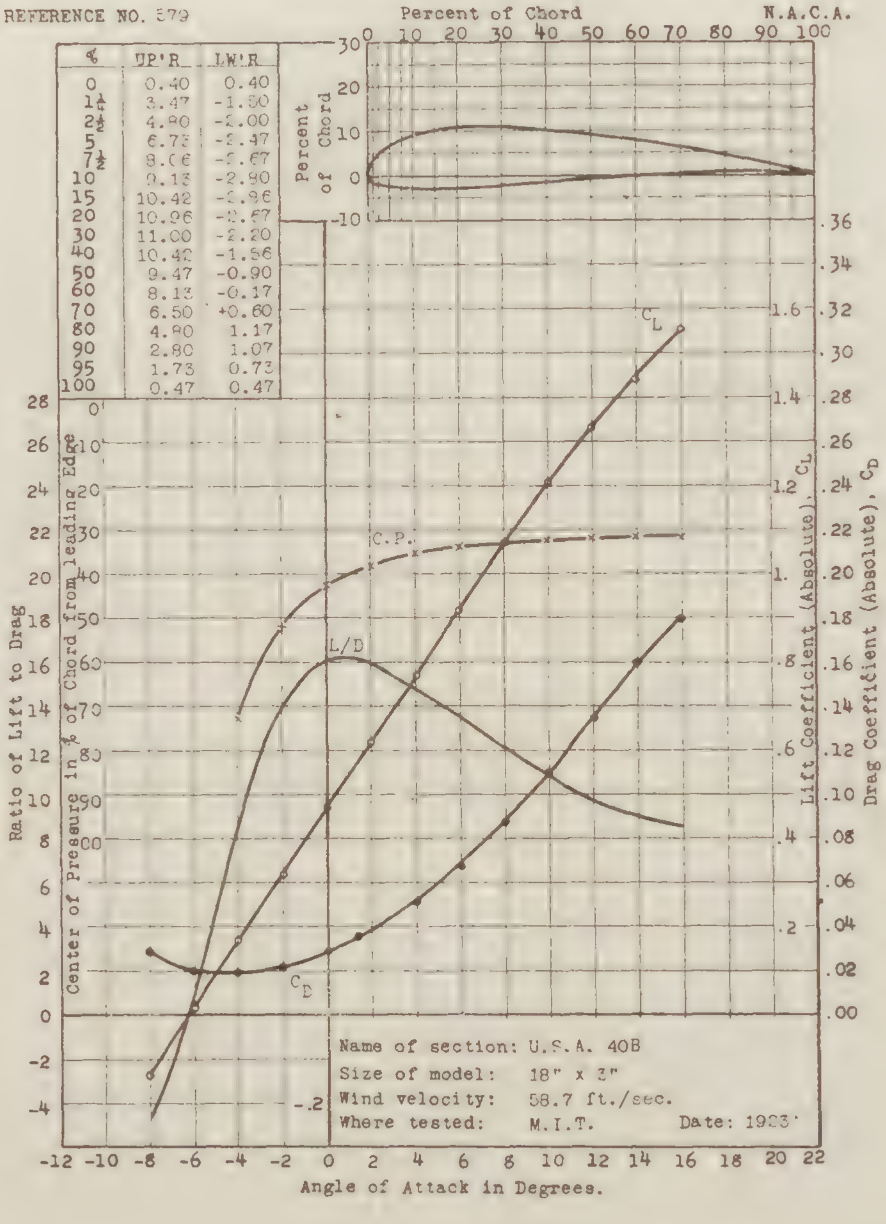
Ordinates for section at center of span

%	UP'R	LW'R
0	4.33	4.33
1¼	8.09	1.62
2½	9.58	0.95
5	11.83	0.42
7½	13.58	0.22
10	14.88	0.10
15	16.60	0.00
20	17.72	0.08
30	18.43	0.25
40	17.86	0.44
50	16.16	0.60
60	13.81	0.67
70	11.12	0.65
80	7.88	0.55
90	4.33	0.32
95	2.39	0.19
100	0.43	0.00

All in % of span
a - 50.00%
b - 22.22%
c - 13.33%
d - 6.23%
e - 2.67%

Name of section: U.S.A. 35
Size of model: 18" x 4" & 2.4"
Wind velocity: 58.7 ft./sec.
Where tested: M.I.T. Date: 1922

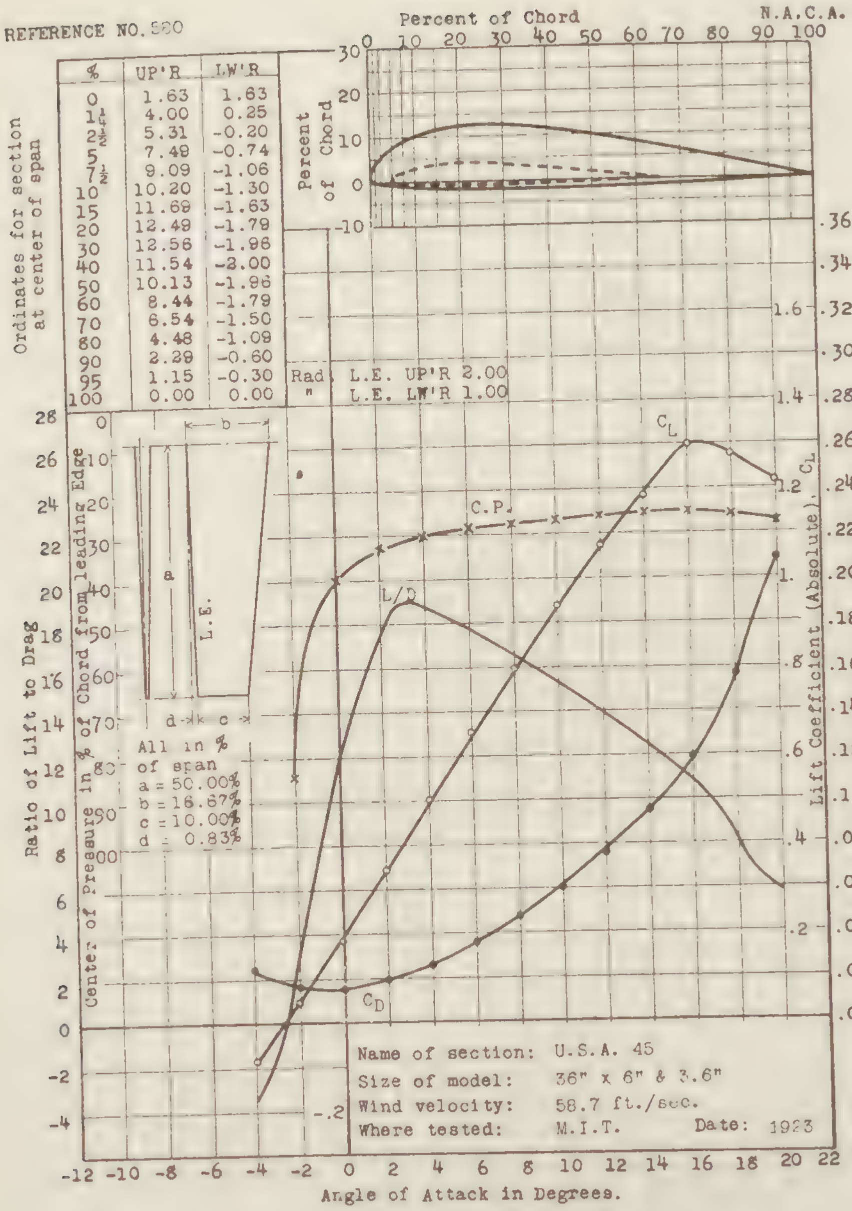
REFERENCE NO. 579



%	UP'R	LW'R
0	0.40	0.40
1¼	3.47	-1.50
2½	4.80	-2.00
5	6.73	-2.47
7½	8.06	-2.67
10	9.13	-2.80
15	10.42	-2.96
20	10.96	-2.67
30	11.00	-2.20
40	10.42	-1.56
50	9.47	-0.90
60	8.13	-0.17
70	6.50	+0.60
80	4.80	1.17
90	2.80	1.07
95	1.73	0.73
100	0.47	0.47

Name of section: U.S.A. 40B
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: M.I.T. Date: 1923

REFERENCE NO. 580

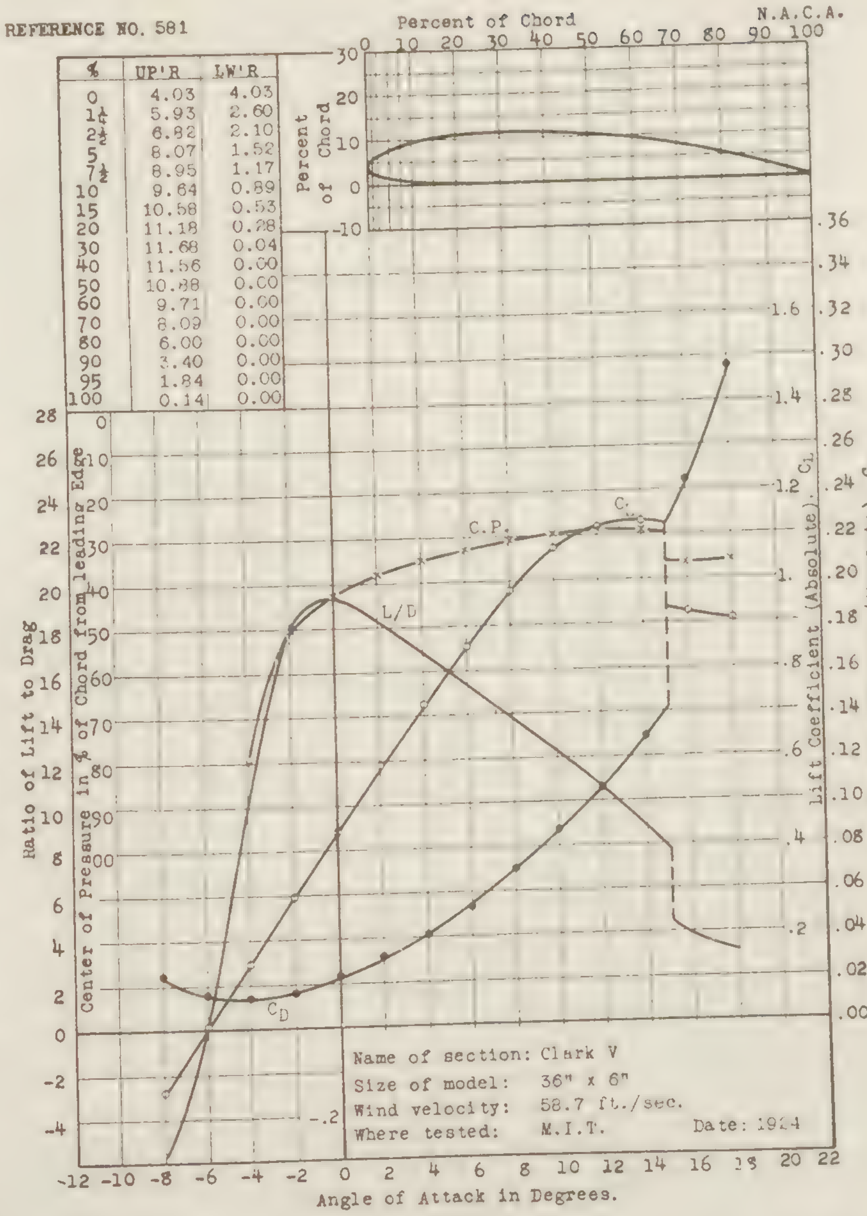


%	UP'R	LW'R
0	1.63	1.63
1¼	4.00	0.25
2½	5.31	-0.20
5	7.48	-0.74
7½	9.09	-1.06
10	10.20	-1.30
15	11.68	-1.63
20	12.49	-1.79
30	12.56	-1.96
40	11.54	-2.00
50	10.13	-1.96
60	8.44	-1.79
70	6.54	-1.50
80	4.48	-1.09
90	2.29	-0.60
95	1.15	-0.30
100	0.00	0.00

Rad. L.E. UP'R 2.00
" L.E. LW'R 1.00

Name of section: U.S.A. 45
Size of model: 36" x 6" & 3.6"
Wind velocity: 58.7 ft./sec.
Where tested: M.I.T. Date: 1923

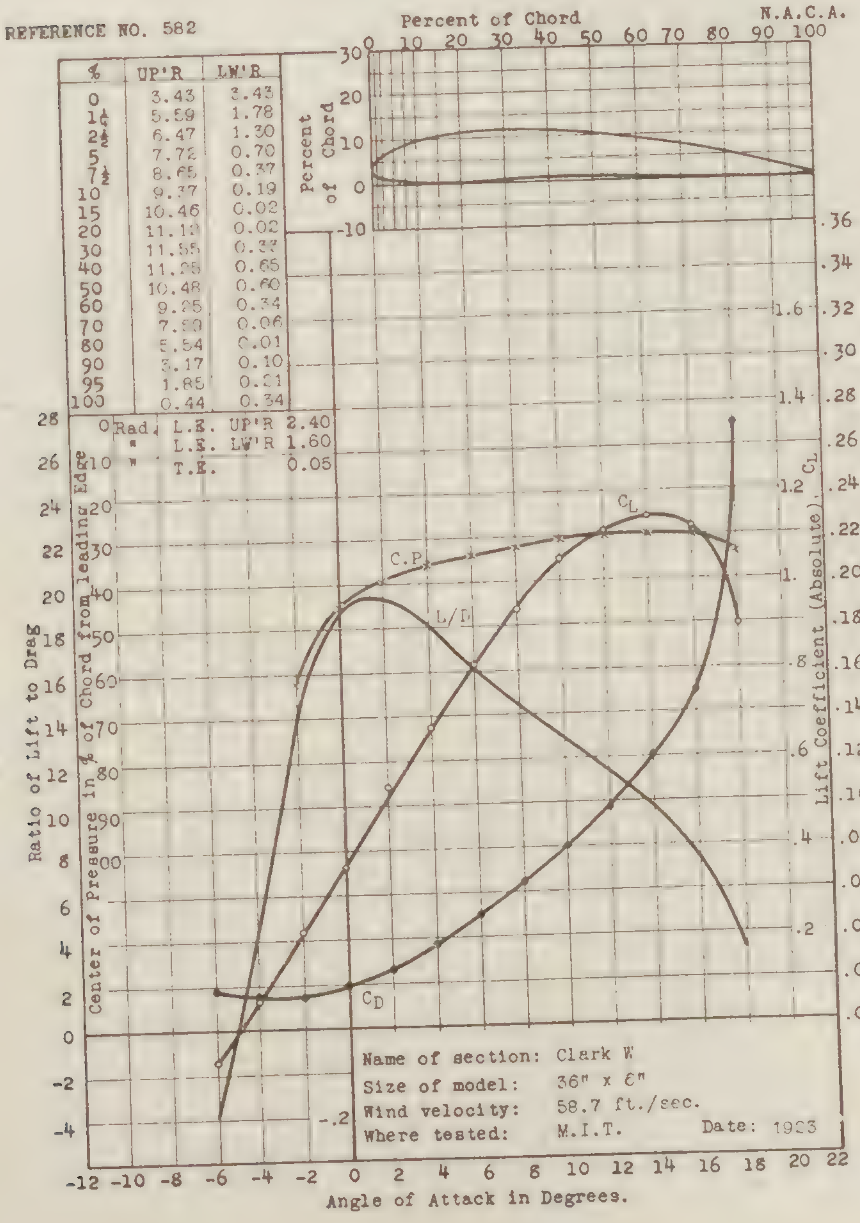
REFERENCE NO. 581



%	UP'R	LW'R
0	4.03	4.03
1¼	5.93	2.60
2½	6.82	2.10
5	8.07	1.52
7½	8.95	1.17
10	9.64	0.89
15	10.58	0.53
20	11.18	0.28
30	11.68	0.04
40	11.56	0.00
50	10.88	0.00
60	9.71	0.00
70	8.09	0.00
80	6.00	0.00
90	3.40	0.00
95	1.84	0.00
100	0.14	0.00

Name of section: Clark V
Size of model: 36" x 6"
Wind velocity: 58.7 ft./sec.
Where tested: M.I.T. Date: 1924

REFERENCE NO. 582

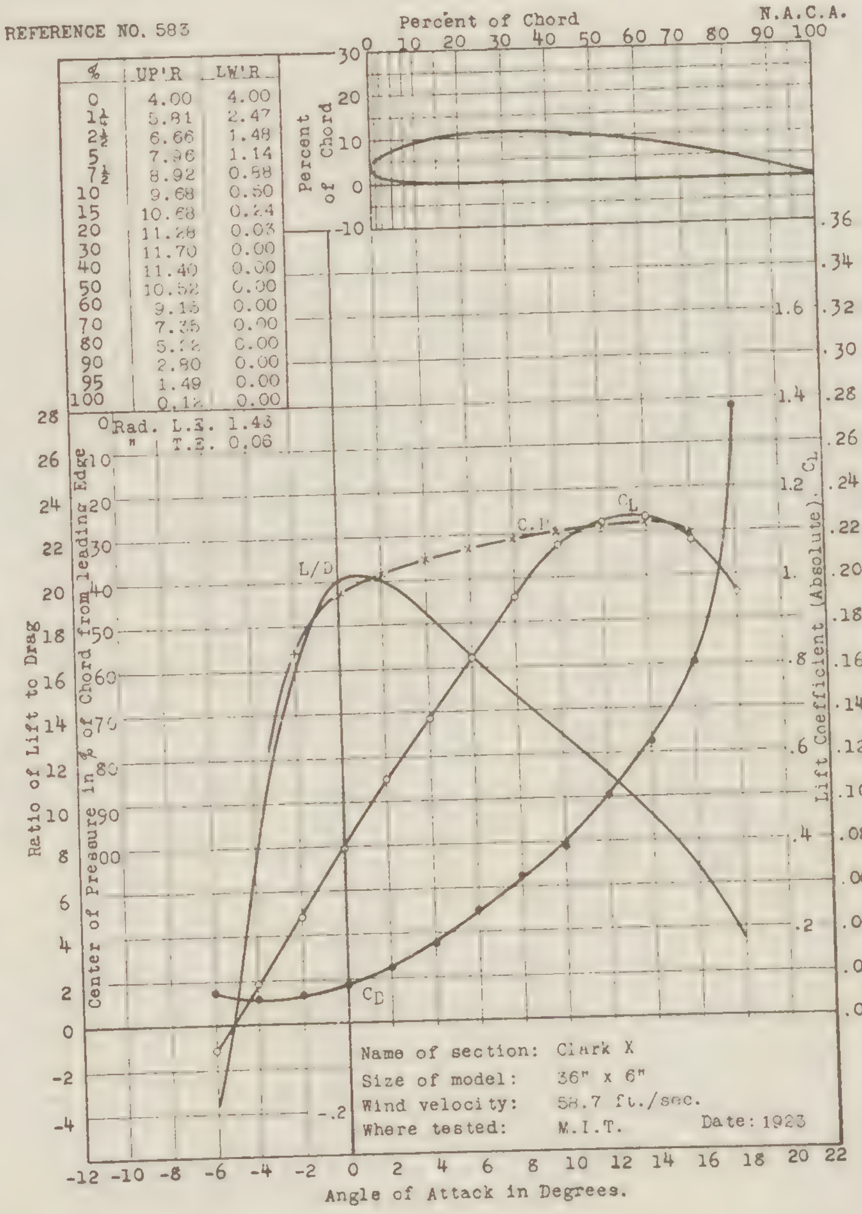


%	UP'R	LW'R
0	3.43	3.43
1¼	5.59	1.78
2½	6.47	1.30
5	7.72	0.70
7½	8.65	0.37
10	9.37	0.19
15	10.46	0.02
20	11.12	0.02
30	11.55	0.37
40	11.25	0.65
50	10.48	0.60
60	9.25	0.34
70	7.50	0.06
80	5.54	0.01
90	3.17	0.10
95	1.85	0.21
100	0.44	0.34

Rad. L.E. UP'R 2.40
" L.E. LW'R 1.60
" T.E. 0.05

Name of section: Clark W
Size of model: 36" x 6"
Wind velocity: 58.7 ft./sec.
Where tested: M.I.T. Date: 1923

REFERENCE NO. 583

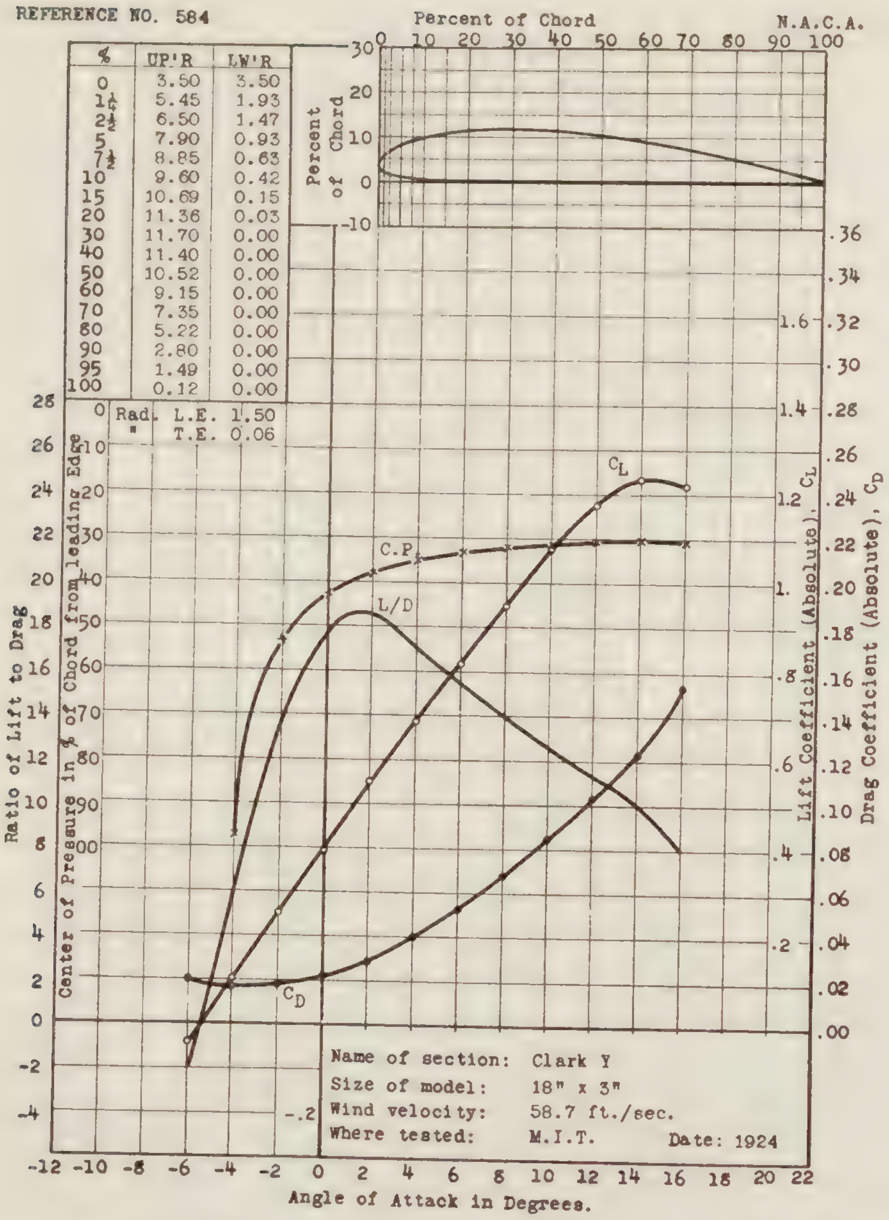


%	UP'R	LW'R
0	4.00	4.00
1¼	5.81	2.47
2½	6.66	1.48
5	7.96	1.14
7½	8.92	0.58
10	9.68	0.50
15	10.68	0.24
20	11.28	0.03
30	11.70	0.00
40	11.40	0.00
50	10.52	0.00
60	9.15	0.00
70	7.35	0.00
80	5.12	0.00
90	2.80	0.00
95	1.49	0.00
100	0.12	0.00

Rad. L.E. 1.43
" T.E. 0.06

Name of section: Clark X
Size of model: 36" x 6"
Wind velocity: 58.7 ft./sec.
Where tested: M.I.T. Date: 1923

REFERENCE NO. 584

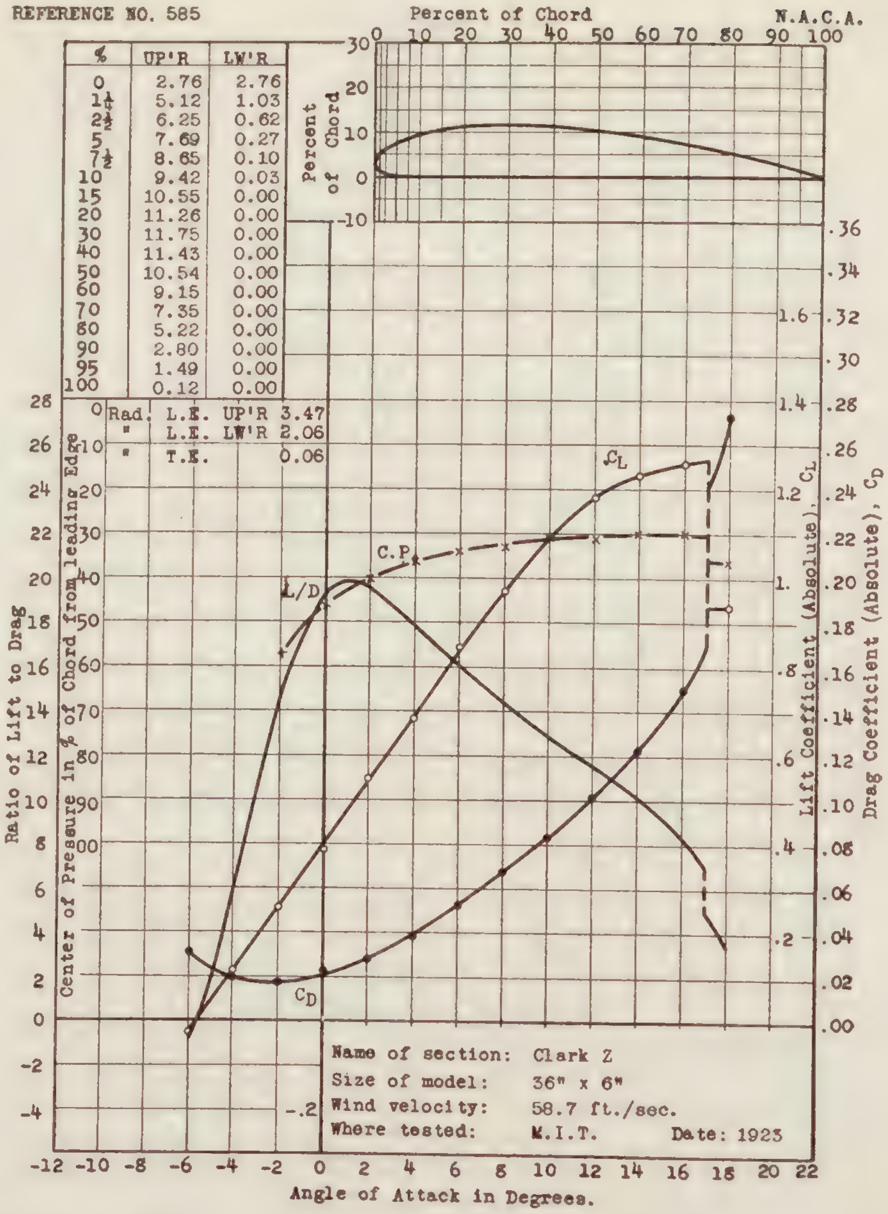


%	UP'R	LW'R
0	3.50	3.50
1¼	5.45	1.93
2½	6.50	1.47
5	7.90	0.93
7½	8.85	0.63
10	9.60	0.42
15	10.69	0.15
20	11.36	0.03
30	11.70	0.00
40	11.40	0.00
50	10.52	0.00
60	9.15	0.00
70	7.35	0.00
80	5.22	0.00
90	2.80	0.00
95	1.49	0.00
100	0.12	0.00

Rad. L.E. 1.50
" T.E. 0.06

Name of section: Clark Y
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: M.I.T. Date: 1924

REFERENCE NO. 585

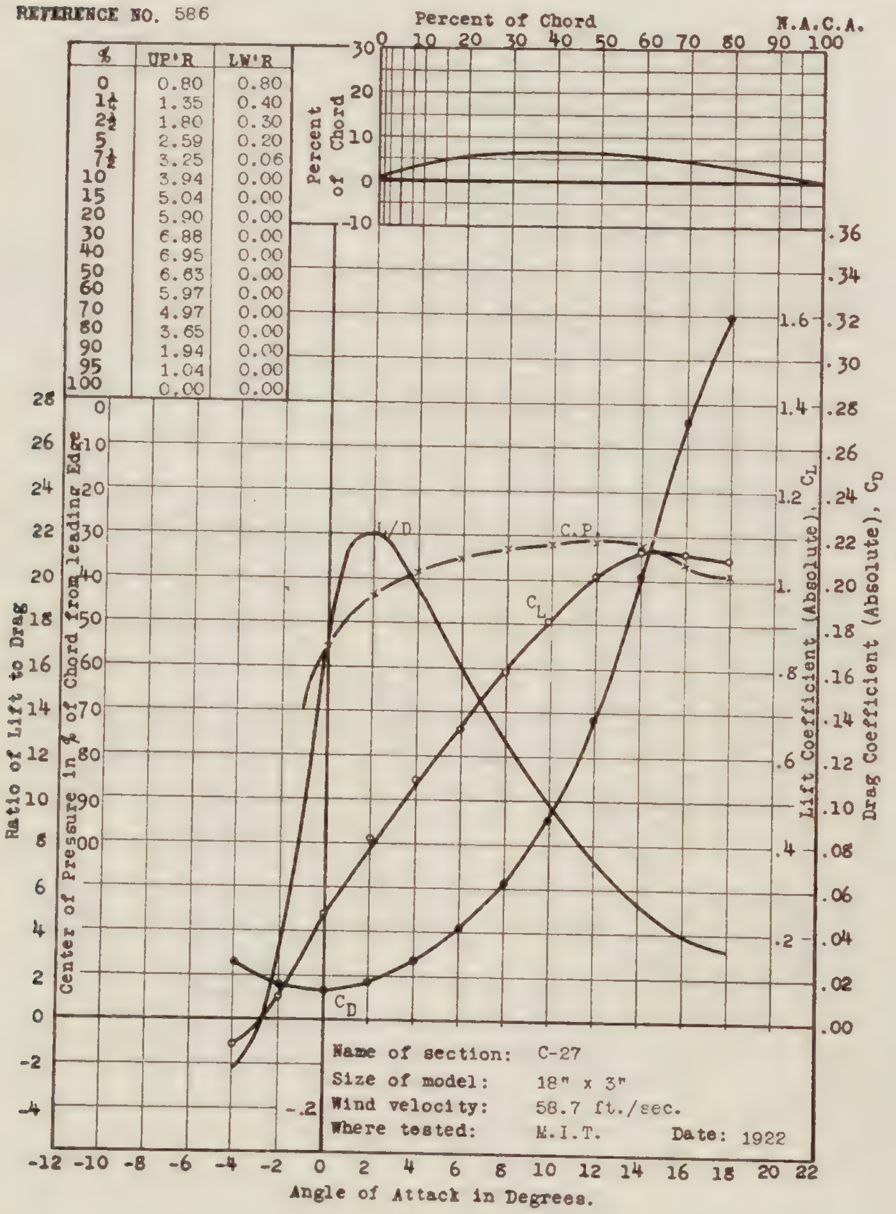


%	UP'R	LW'R
0	2.76	2.76
1¼	5.12	1.03
2½	6.25	0.62
5	7.69	0.27
7½	8.65	0.10
10	9.42	0.03
15	10.55	0.00
20	11.26	0.00
30	11.75	0.00
40	11.43	0.00
50	10.54	0.00
60	9.15	0.00
70	7.35	0.00
80	5.22	0.00
90	2.80	0.00
95	1.49	0.00
100	0.12	0.00

Rad. L.E. UP'R 3.47
" L.E. LW'R 2.06
" T.E. 0.06

Name of section: Clark Z
Size of model: 36" x 6"
Wind velocity: 58.7 ft./sec.
Where tested: M.I.T. Date: 1923

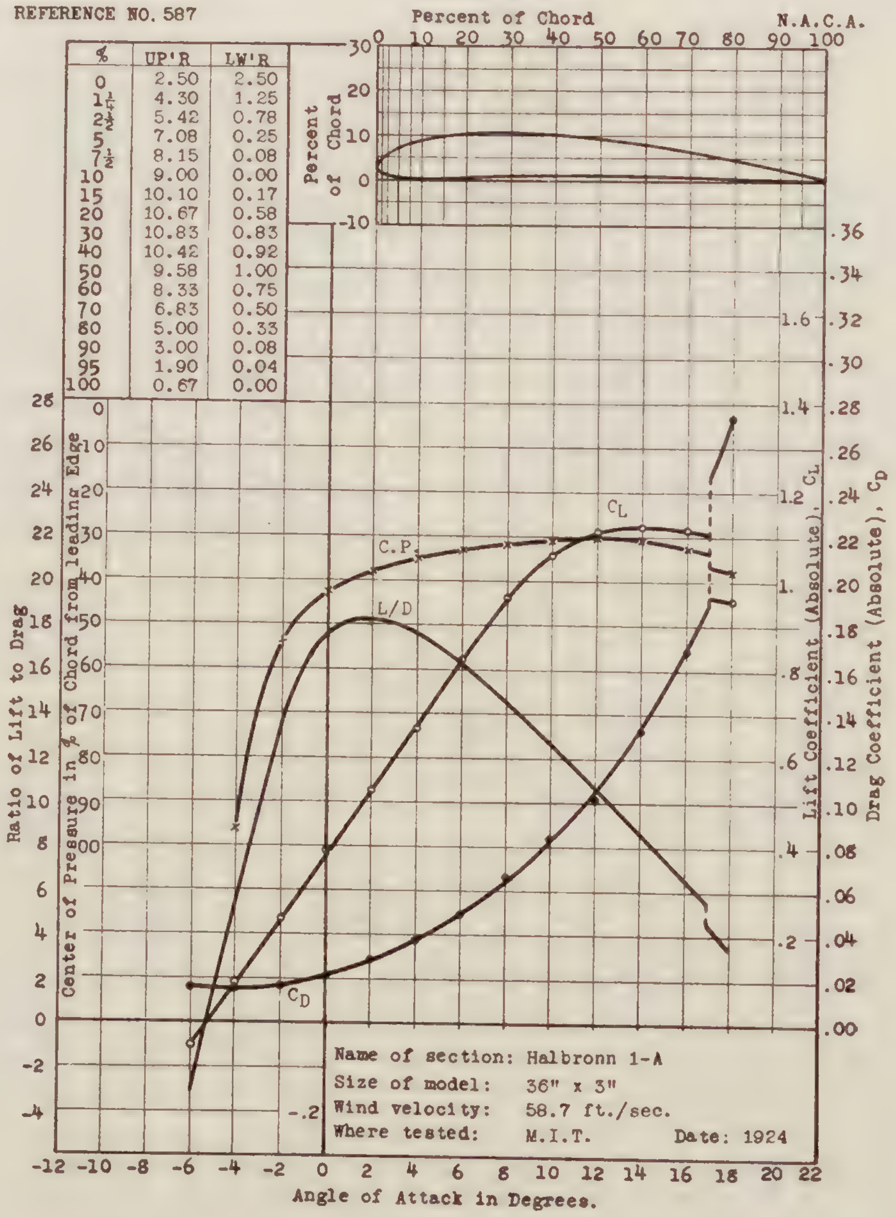
REFERENCE NO. 586



%	UP'R	LW'R
0	0.80	0.80
1¼	1.35	0.40
2½	1.80	0.30
5	2.59	0.20
7½	3.25	0.06
10	3.94	0.00
15	5.04	0.00
20	5.90	0.00
30	6.88	0.00
40	6.95	0.00
50	6.63	0.00
60	5.97	0.00
70	4.97	0.00
80	3.65	0.00
90	1.94	0.00
95	1.04	0.00
100	0.00	0.00

Name of section: C-27
Size of model: 18" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: M.I.T. Date: 1922

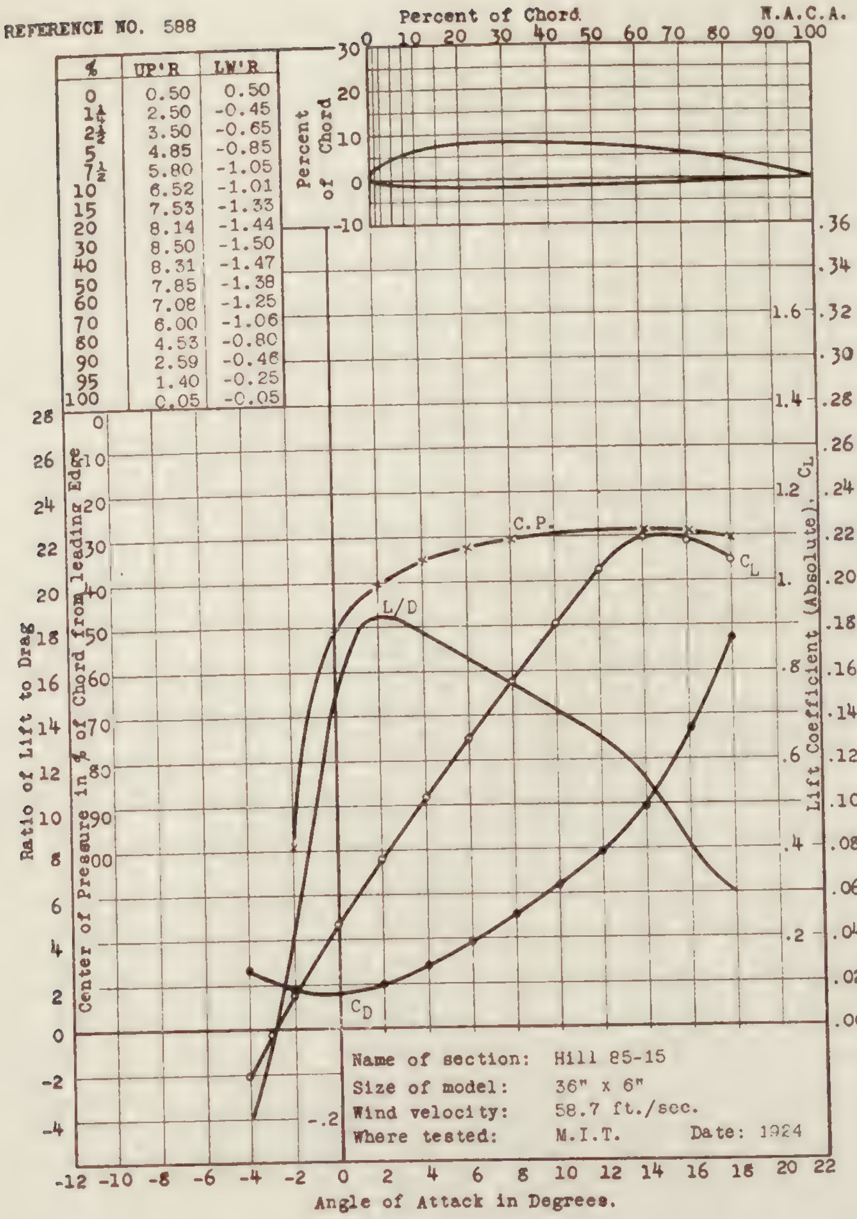
REFERENCE NO. 587



%	UP'R	LW'R
0	2.50	2.50
1¼	4.30	1.25
2½	5.42	0.78
5	7.08	0.25
7½	8.15	0.08
10	9.00	0.00
15	10.10	0.17
20	10.67	0.58
30	10.83	0.83
40	10.42	0.92
50	9.58	1.00
60	8.33	0.75
70	6.83	0.50
80	5.00	0.33
90	3.00	0.08
95	1.90	0.04
100	0.67	0.00

Name of section: Halbronn 1-A
Size of model: 36" x 3"
Wind velocity: 58.7 ft./sec.
Where tested: M.I.T. Date: 1924

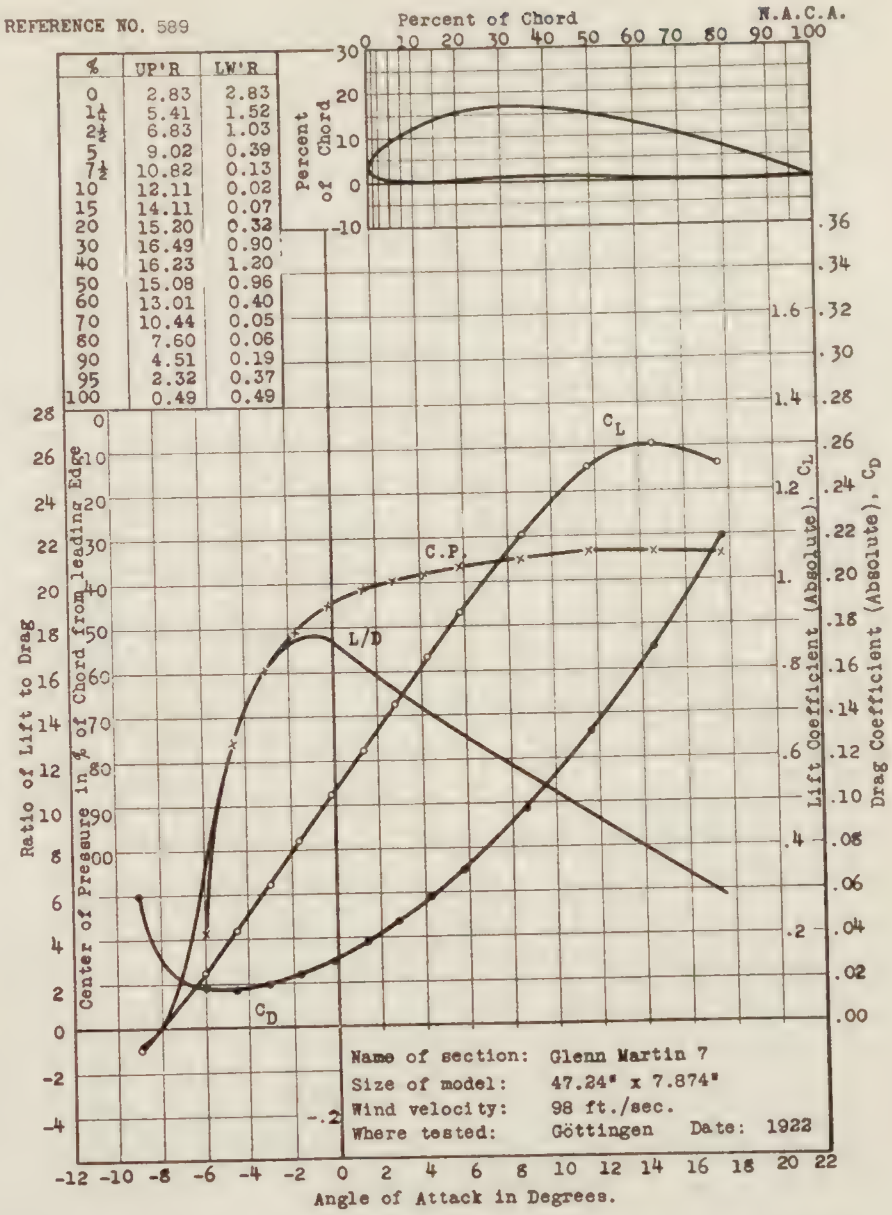
REFERENCE NO. 588



%	UP'R	LW'R
0	0.50	0.50
1¼	2.50	-0.45
2½	3.50	-0.65
5	4.85	-0.85
7½	5.80	-1.05
10	6.52	-1.01
15	7.53	-1.33
20	8.14	-1.44
30	8.50	-1.50
40	8.31	-1.47
50	7.85	-1.38
60	7.08	-1.25
70	6.00	-1.06
80	4.53	-0.80
90	2.59	-0.46
95	1.40	-0.25
100	0.05	-0.05

Name of section: Hill 85-15
Size of model: 36" x 6"
Wind velocity: 58.7 ft./sec.
Where tested: M.I.T. Date: 1924

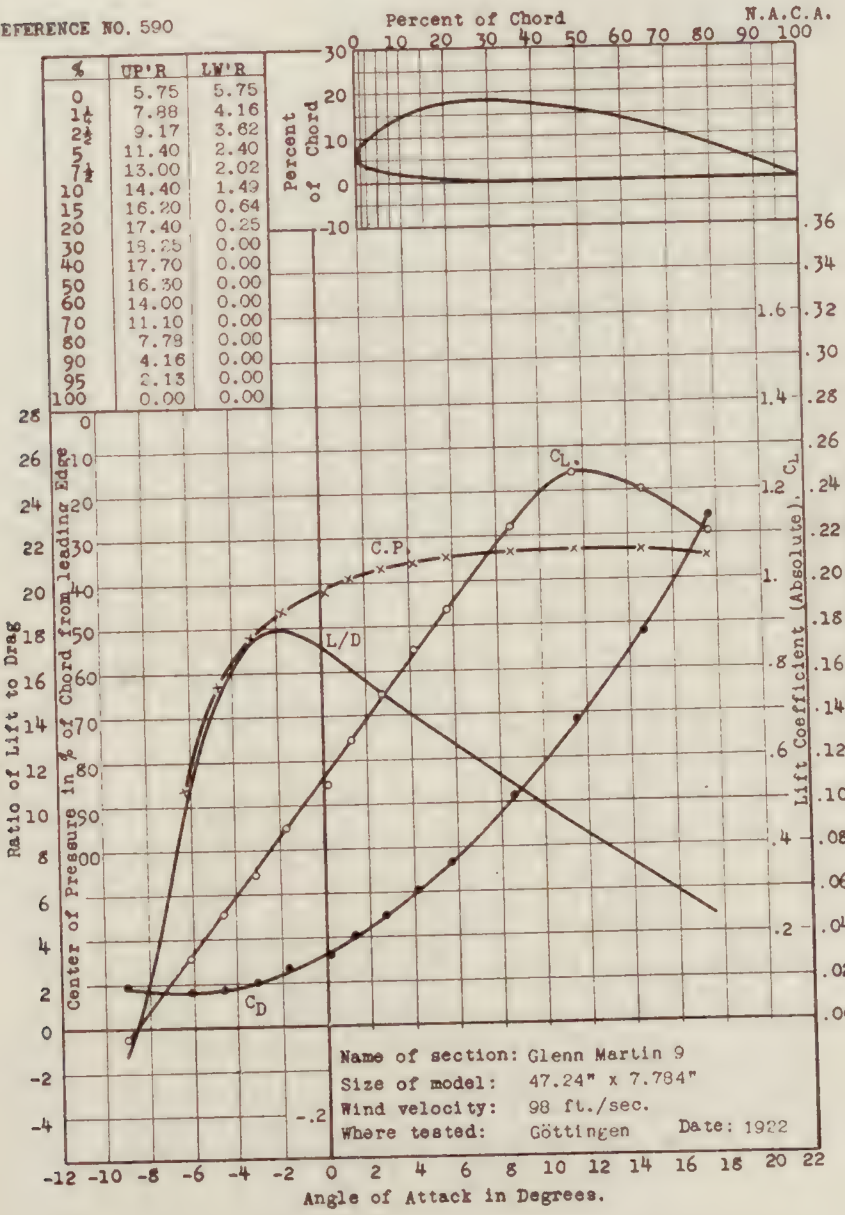
REFERENCE NO. 589



%	UP'R	LW'R
0	2.83	2.83
1¼	5.41	1.52
2½	6.83	1.03
5	9.02	0.39
7½	10.82	0.13
10	12.11	0.02
15	14.11	0.07
20	15.20	0.32
30	16.49	0.90
40	16.23	1.20
50	15.08	0.96
60	13.01	0.40
70	10.44	0.05
80	7.60	0.06
90	4.51	0.19
95	2.32	0.37
100	0.49	0.49

Name of section: Glenn Martin 7
Size of model: 47.24" x 7.874"
Wind velocity: 98 ft./sec.
Where tested: Göttingen Date: 1922

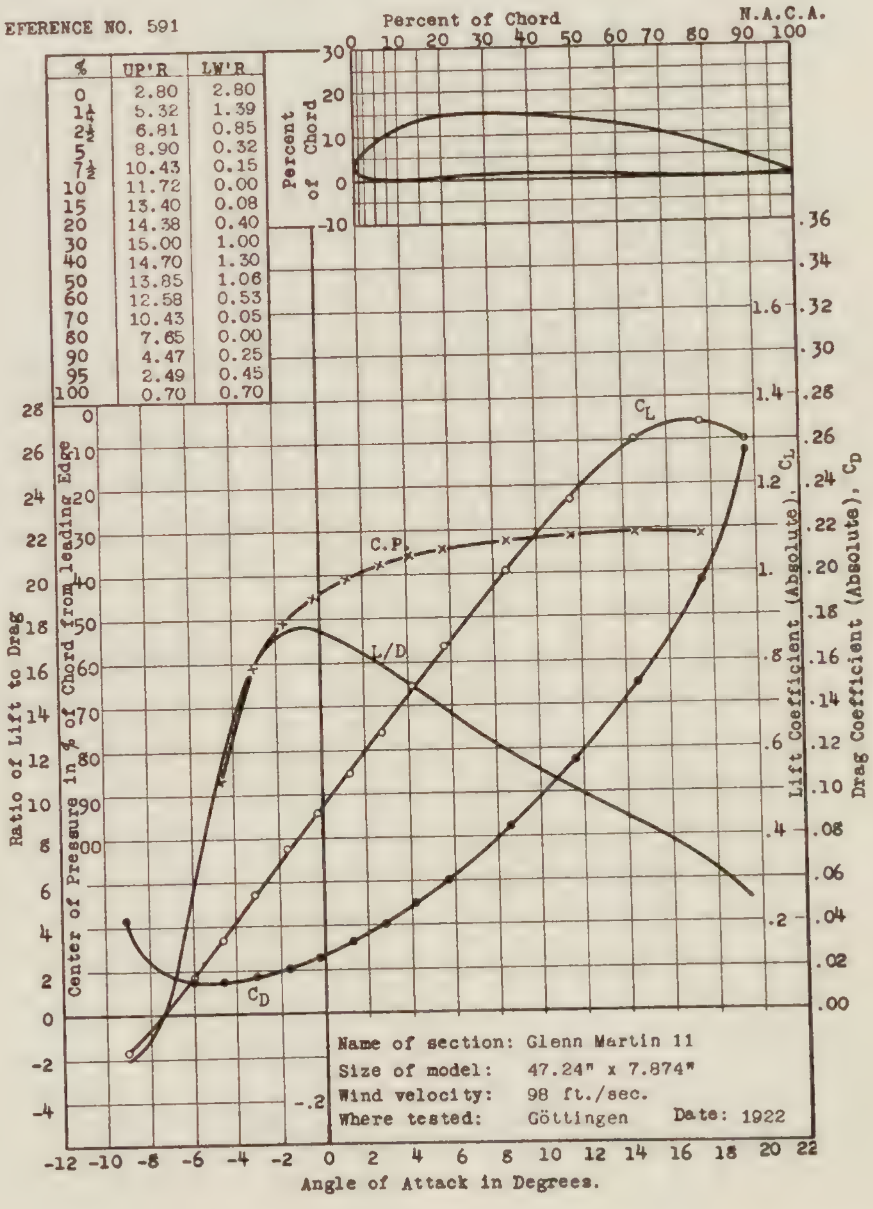
REFERENCE NO. 590



%	UP'R	LW'R
0	5.75	5.75
1¼	7.88	4.16
2½	9.17	3.62
5	11.40	2.40
7½	13.00	2.02
10	14.40	1.49
15	16.20	0.64
20	17.40	0.25
30	18.25	0.00
40	17.70	0.00
50	16.30	0.00
60	14.00	0.00
70	11.10	0.00
80	7.78	0.00
90	4.16	0.00
95	2.13	0.00
100	0.00	0.00

Name of section: Glenn Martin 9
Size of model: 47.24" x 7.784"
Wind velocity: 98 ft./sec.
Where tested: Göttingen Date: 1922

EFERENCE NO. 591

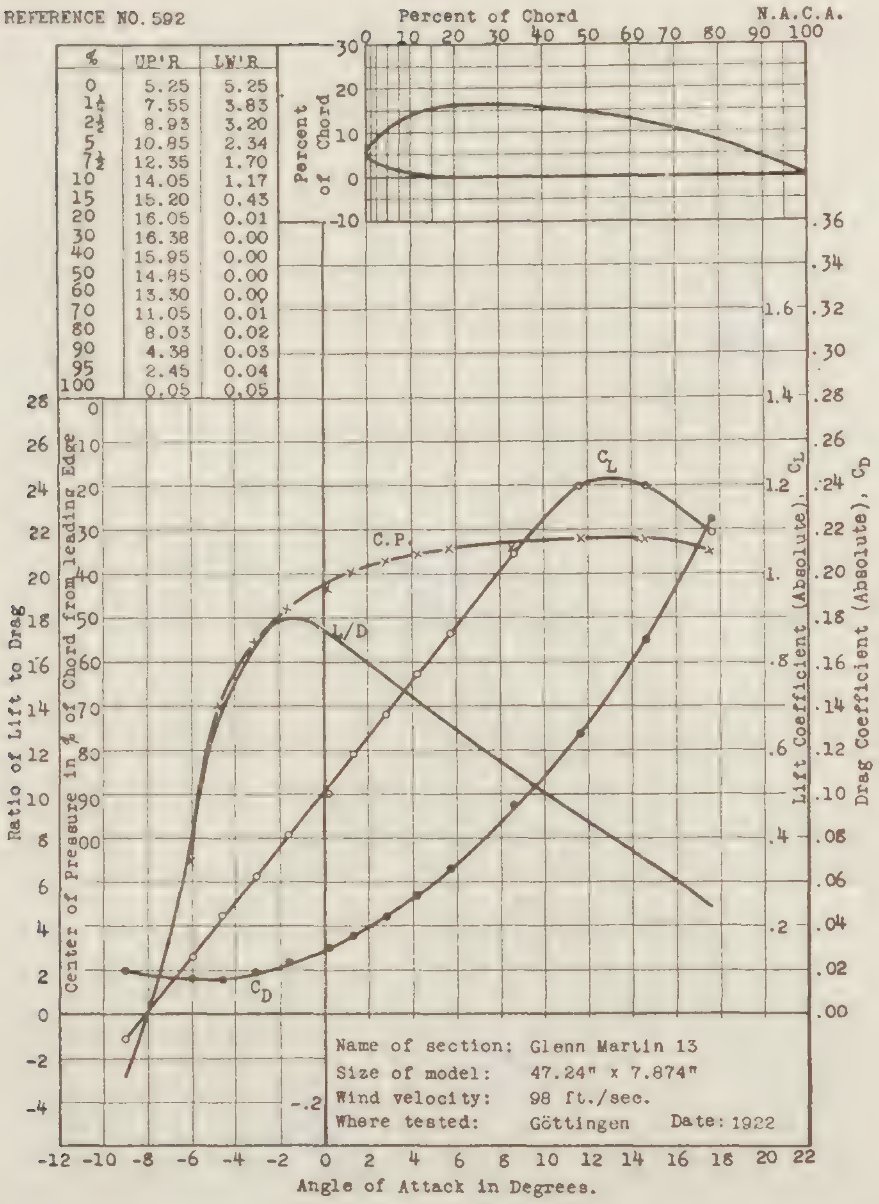


%	UP'R	LW'R
0	2.80	2.80
1¼	5.32	1.39
2½	6.81	0.85
5	8.90	0.32
7½	10.43	0.15
10	11.72	0.00
15	13.40	0.08
20	14.38	0.40
30	15.00	1.00
40	14.70	1.30
50	13.85	1.06
60	12.58	0.53
70	10.43	0.05
80	7.65	0.00
90	4.47	0.25
95	2.49	0.45
100	0.70	0.70

Name of section: Glenn Martin 11
Size of model: 47.24" x 7.874"
Wind velocity: 98 ft./sec.
Where tested: Göttingen Date: 1922

REFERENCE NO. 592

N.A.C.A.

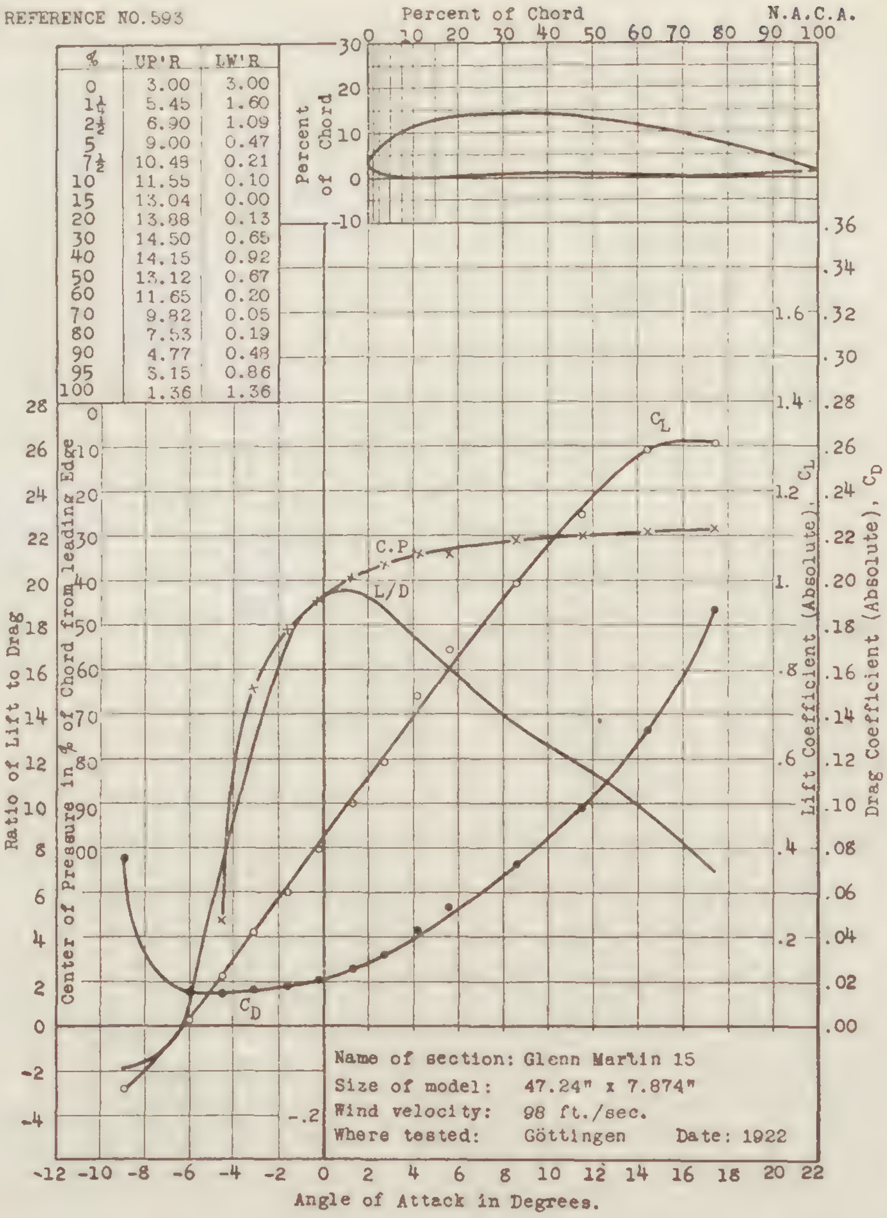


%	UP'R	LW'R
0	5.25	5.25
1¼	7.55	3.83
2½	8.93	3.20
5	10.85	2.34
7½	12.35	1.70
10	14.05	1.17
15	15.20	0.43
20	16.05	0.01
30	16.38	0.00
40	15.95	0.00
50	14.85	0.00
60	13.30	0.00
70	11.05	0.01
80	8.03	0.02
90	4.38	0.03
95	2.45	0.04
100	0.05	0.05

Name of section: Glenn Martin 13
Size of model: 47.24" x 7.874"
Wind velocity: 98 ft./sec.
Where tested: Göttingen Date: 1922

REFERENCE NO. 593

N.A.C.A.

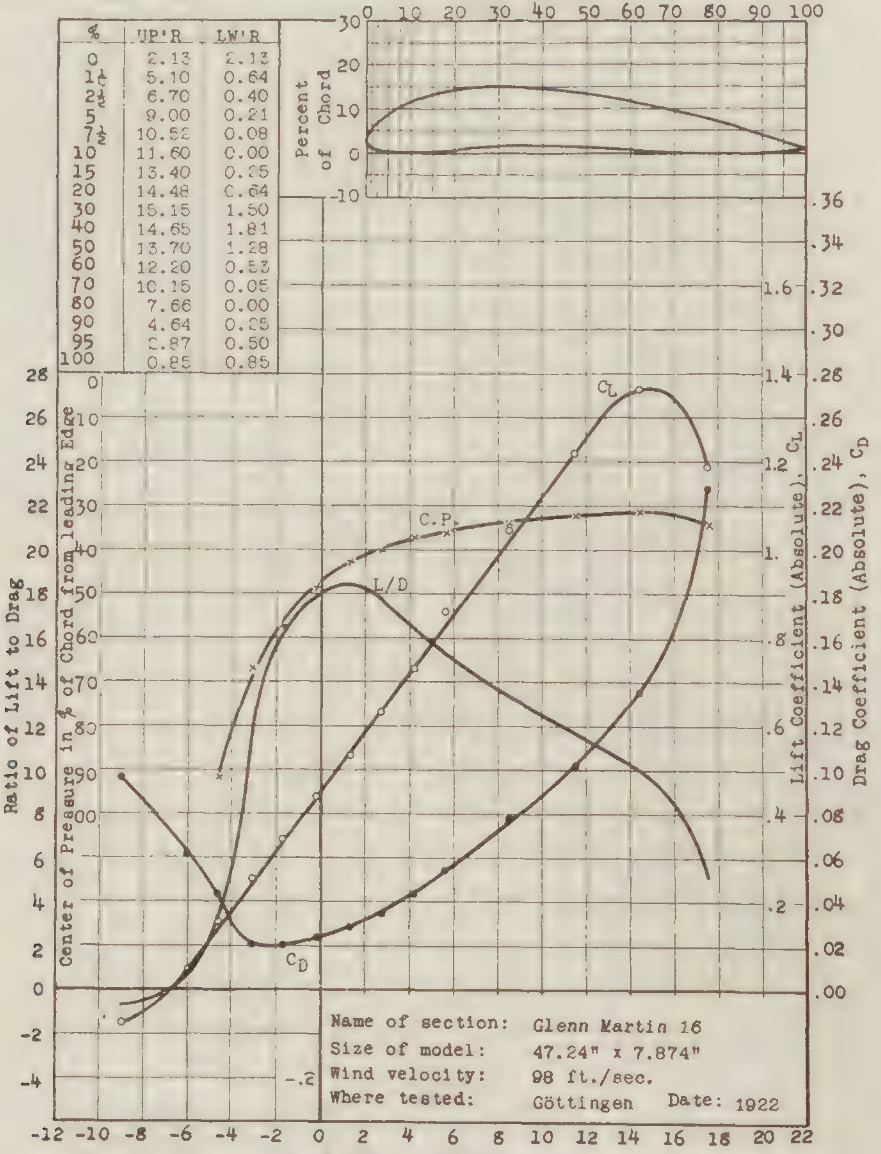


%	UP'R	LW'R
0	3.00	3.00
1¼	5.45	1.60
2½	6.90	1.09
5	9.00	0.47
7½	10.48	0.21
10	11.55	0.10
15	13.04	0.00
20	13.88	0.13
30	14.50	0.65
40	14.15	0.92
50	13.12	0.67
60	11.65	0.20
70	9.82	0.05
80	7.53	0.19
90	4.77	0.48
95	3.15	0.86
100	1.36	1.36

Name of section: Glenn Martin 15
Size of model: 47.24" x 7.874"
Wind velocity: 98 ft./sec.
Where tested: Göttingen Date: 1922

REFERENCE NO. 594

N.A.C.A.

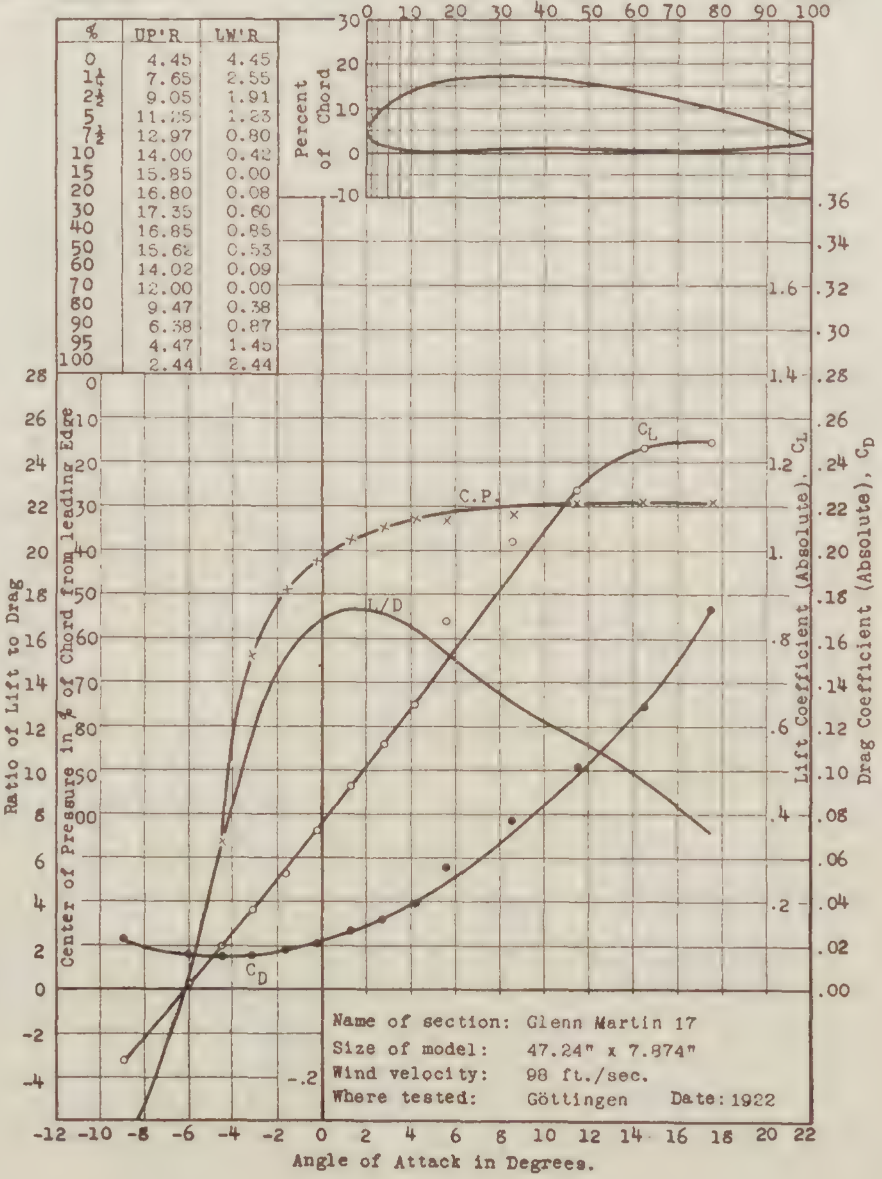


%	UP'R	LW'R
0	2.13	2.13
1¼	5.10	0.64
2½	6.70	0.40
5	9.00	0.21
7½	10.52	0.08
10	11.60	0.00
15	13.40	0.25
20	14.48	0.64
30	15.15	1.50
40	14.65	1.81
50	13.70	1.28
60	12.20	0.53
70	10.15	0.05
80	7.66	0.00
90	4.64	0.25
95	2.87	0.50
100	0.85	0.85

Name of section: Glenn Martin 16
Size of model: 47.24" x 7.874"
Wind velocity: 98 ft./sec.
Where tested: Göttingen Date: 1922

REFERENCE NO. 595

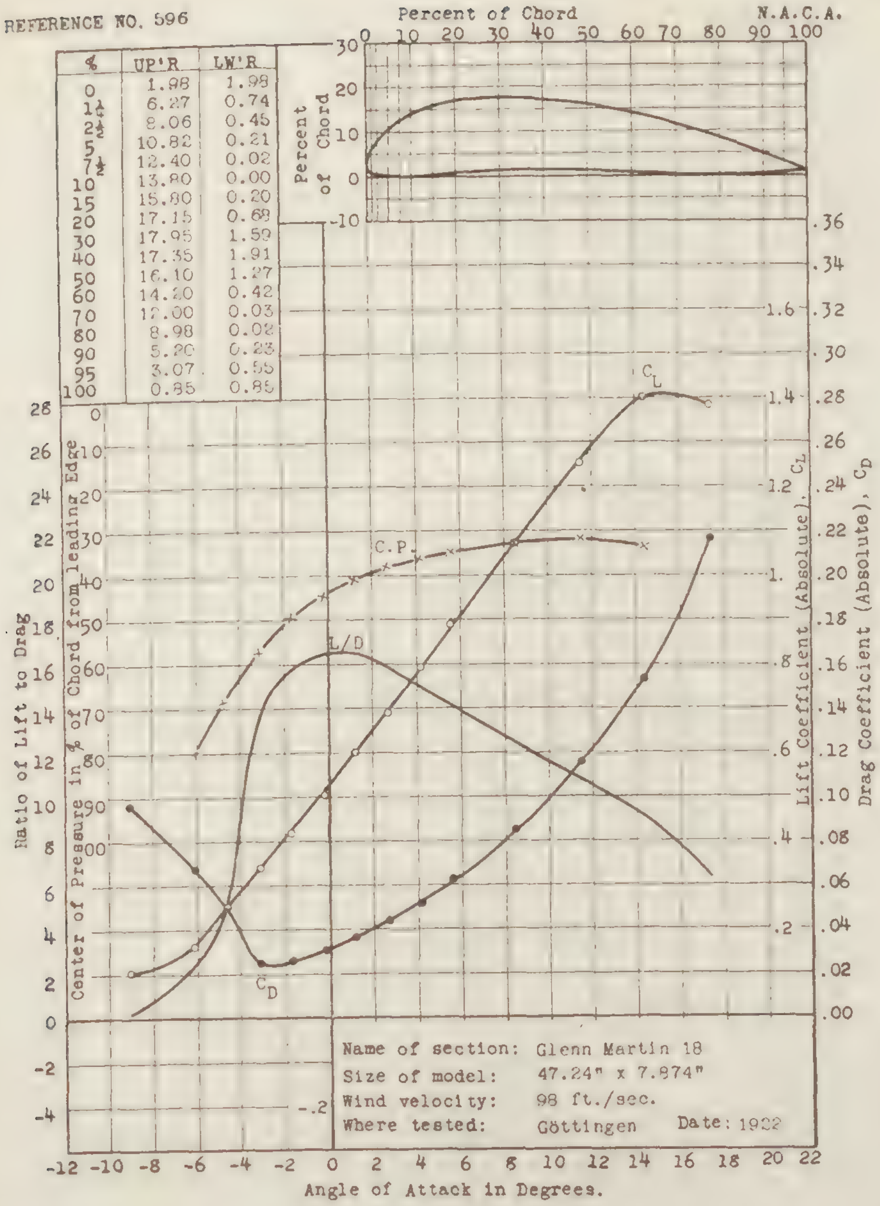
N.A.C.A.



%	UP'R	LW'R
0	4.45	4.45
1¼	7.65	2.55
2½	9.05	1.91
5	11.25	1.23
7½	12.97	0.80
10	14.00	0.42
15	15.85	0.00
20	16.80	0.08
30	17.35	0.60
40	16.85	0.85
50	15.62	0.53
60	14.02	0.09
70	12.00	0.00
80	9.47	0.38
90	6.38	0.87
95	4.47	1.45
100	2.44	2.44

Name of section: Glenn Martin 17
Size of model: 47.24" x 7.874"
Wind velocity: 98 ft./sec.
Where tested: Göttingen Date: 1922

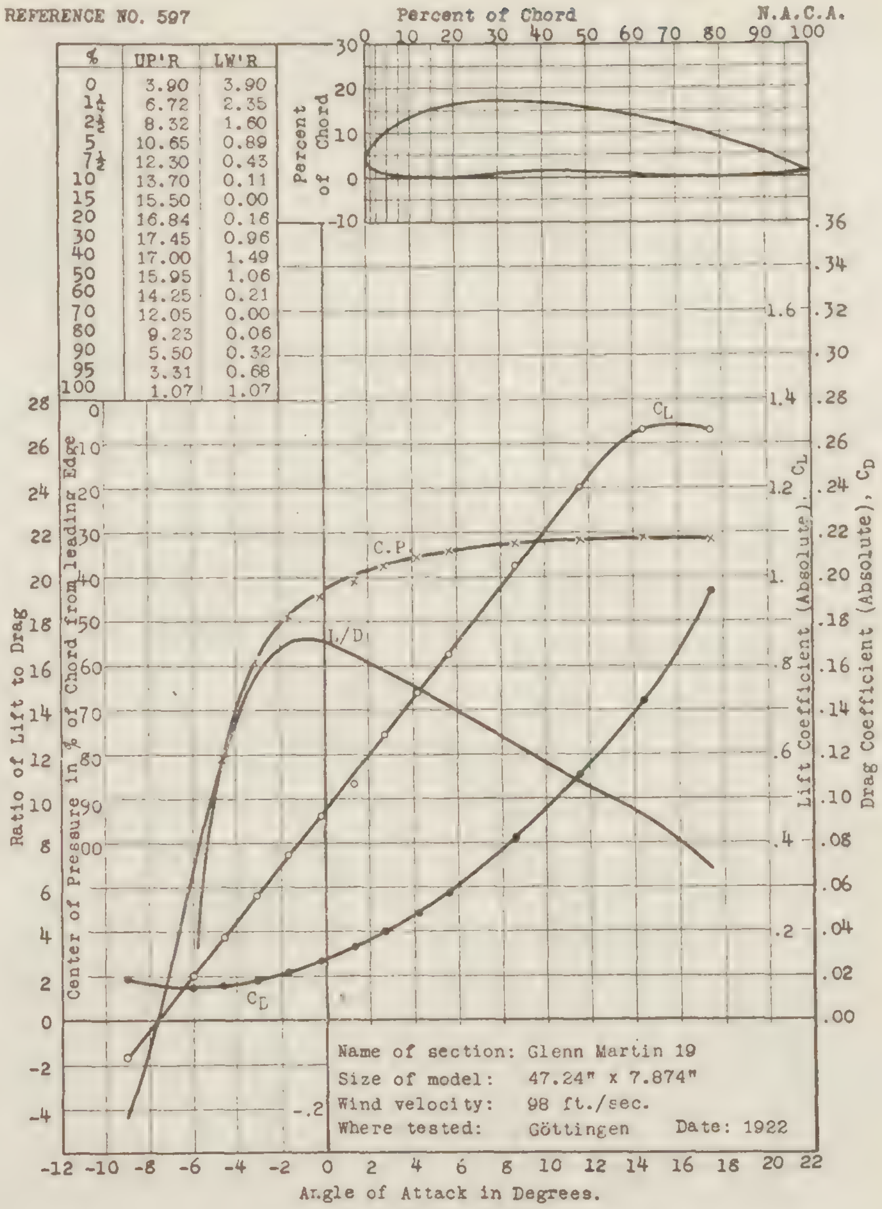
REFERENCE NO. 596



%	UP'R	LW'R
0	1.98	1.98
1¼	6.27	0.74
2½	8.06	0.45
5	10.82	0.21
7½	12.40	0.02
10	13.80	0.00
15	15.80	0.20
20	17.15	0.68
30	17.95	1.59
40	17.35	1.91
50	16.10	1.27
60	14.20	0.42
70	12.00	0.03
80	8.98	0.02
90	5.20	0.23
95	3.07	0.55
100	0.85	0.85

Name of section: Glenn Martin 18
Size of model: 47.24" x 7.874"
Wind velocity: 98 ft./sec.
Where tested: Göttingen Date: 1922

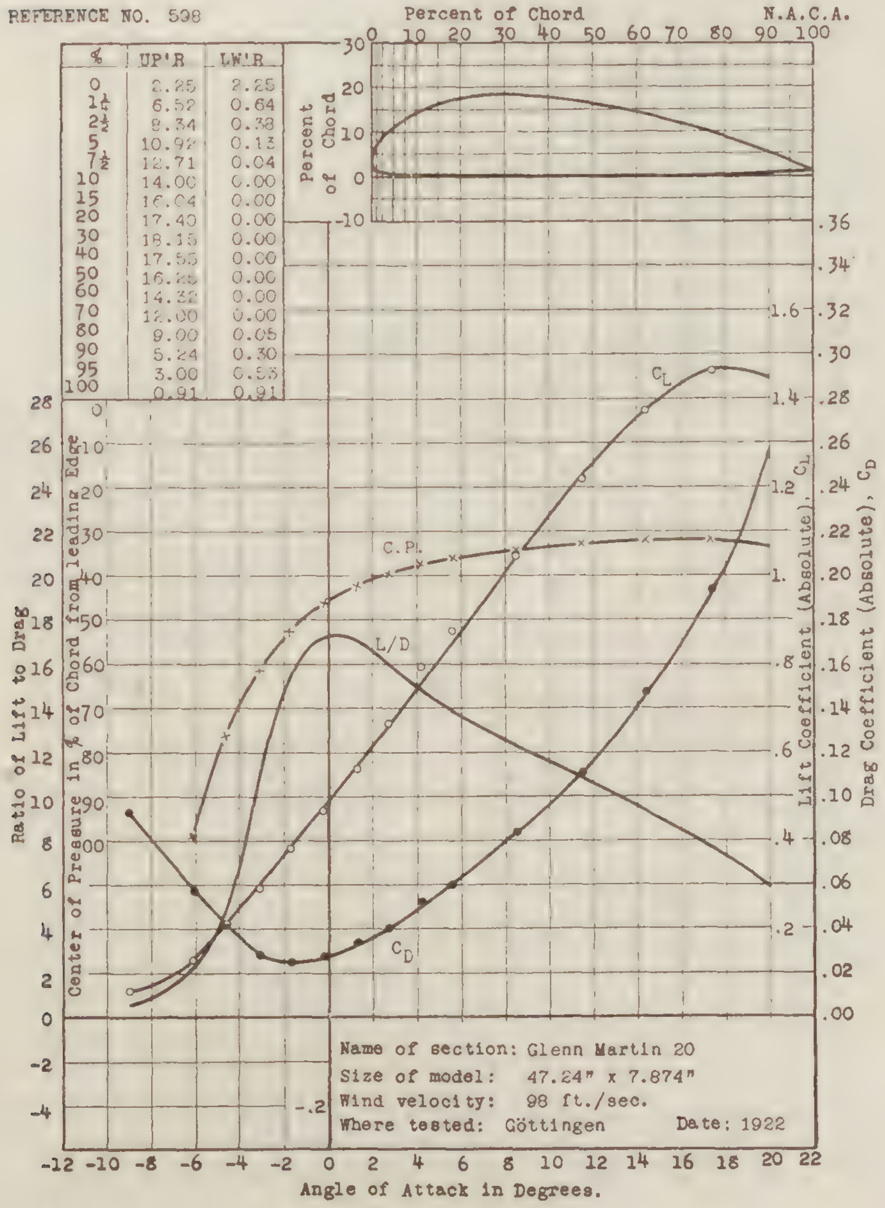
REFERENCE NO. 597



%	UP'R	LW'R
0	3.90	3.90
1¼	6.72	2.35
2½	8.32	1.60
5	10.65	0.89
7½	12.30	0.43
10	13.70	0.11
15	15.50	0.00
20	16.84	0.16
30	17.45	0.96
40	17.00	1.49
50	15.95	1.06
60	14.25	0.21
70	12.05	0.00
80	9.23	0.06
90	5.50	0.32
95	3.31	0.68
100	1.07	1.07

Name of section: Glenn Martin 19
Size of model: 47.24" x 7.874"
Wind velocity: 98 ft./sec.
Where tested: Göttingen Date: 1922

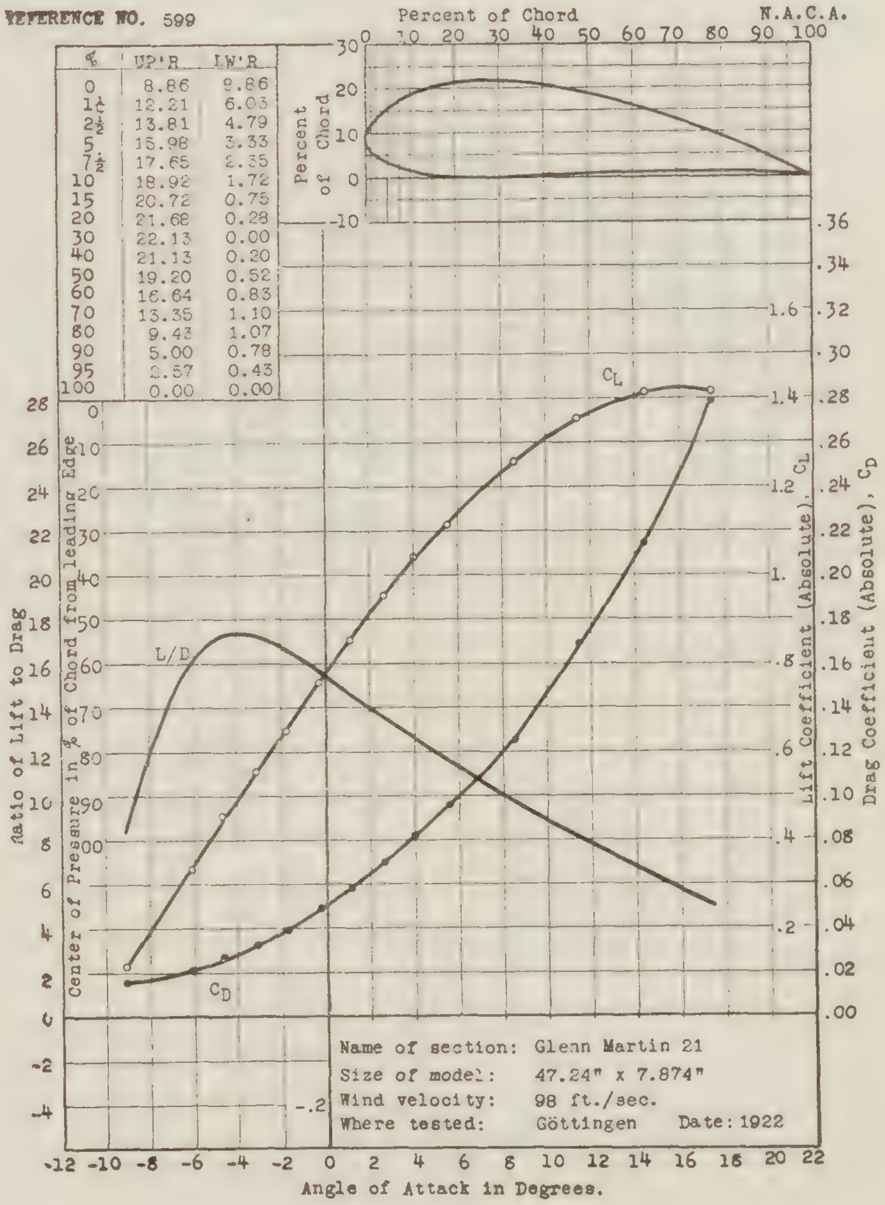
REFERENCE NO. 598



%	UP'R	LW'R
0	2.25	2.25
1¼	6.52	0.64
2½	8.34	0.38
5	10.92	0.13
7½	12.71	0.04
10	14.00	0.00
15	16.04	0.00
20	17.40	0.00
30	18.15	0.00
40	17.55	0.00
50	16.25	0.00
60	14.32	0.00
70	12.00	0.00
80	9.00	0.05
90	5.24	0.30
95	3.00	0.55
100	0.91	0.91

Name of section: Glenn Martin 20
Size of model: 47.24" x 7.874"
Wind velocity: 98 ft./sec.
Where tested: Göttingen Date: 1922

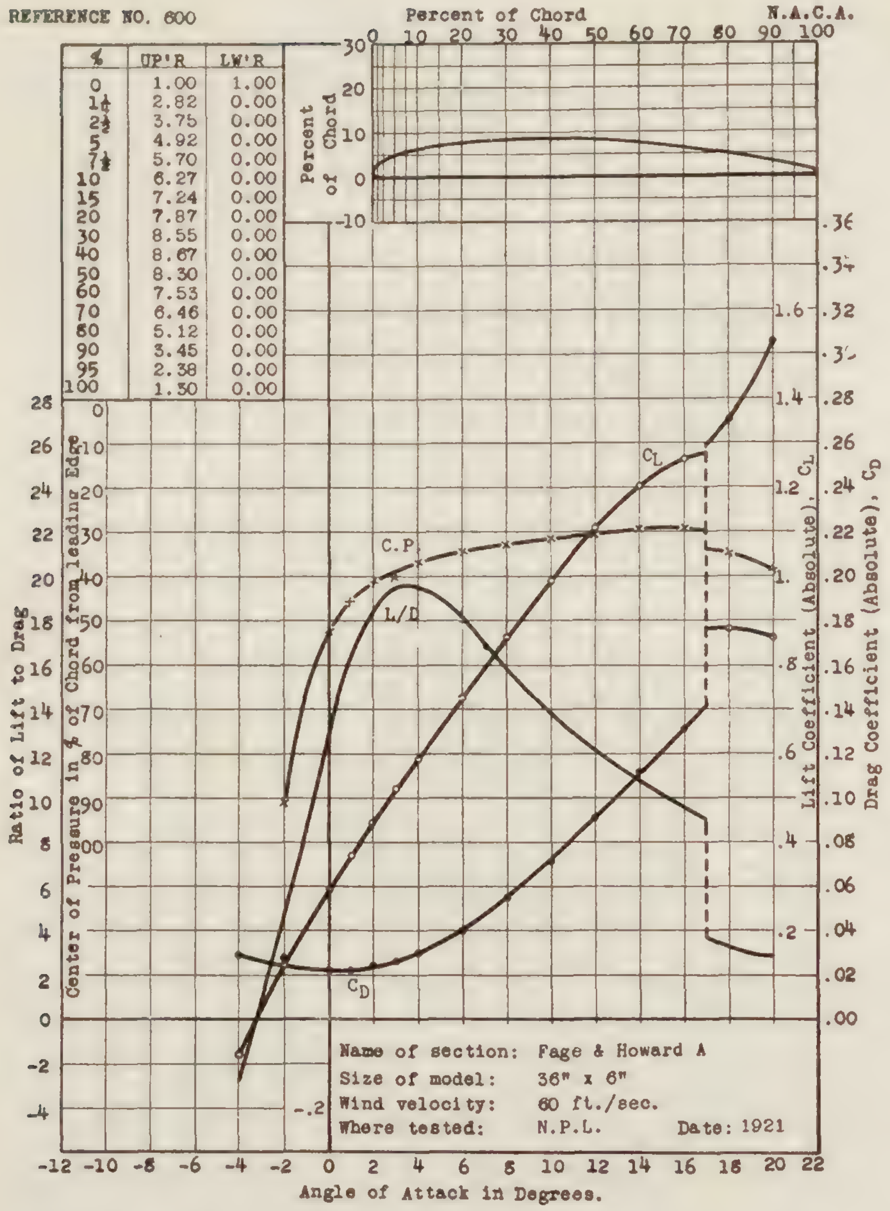
REFERENCE NO. 599



%	UP'R	LW'R
0	8.86	8.86
1¼	12.21	6.03
2½	13.81	4.79
5	15.98	3.33
7½	17.65	2.35
10	18.92	1.72
15	20.72	0.75
20	21.68	0.28
30	22.13	0.00
40	21.13	0.20
50	19.20	0.52
60	16.64	0.83
70	13.35	1.10
80	9.43	1.07
90	5.00	0.78
95	2.57	0.43
100	0.00	0.00

Name of section: Glenn Martin 21
Size of model: 47.24" x 7.874"
Wind velocity: 98 ft./sec.
Where tested: Göttingen Date: 1922

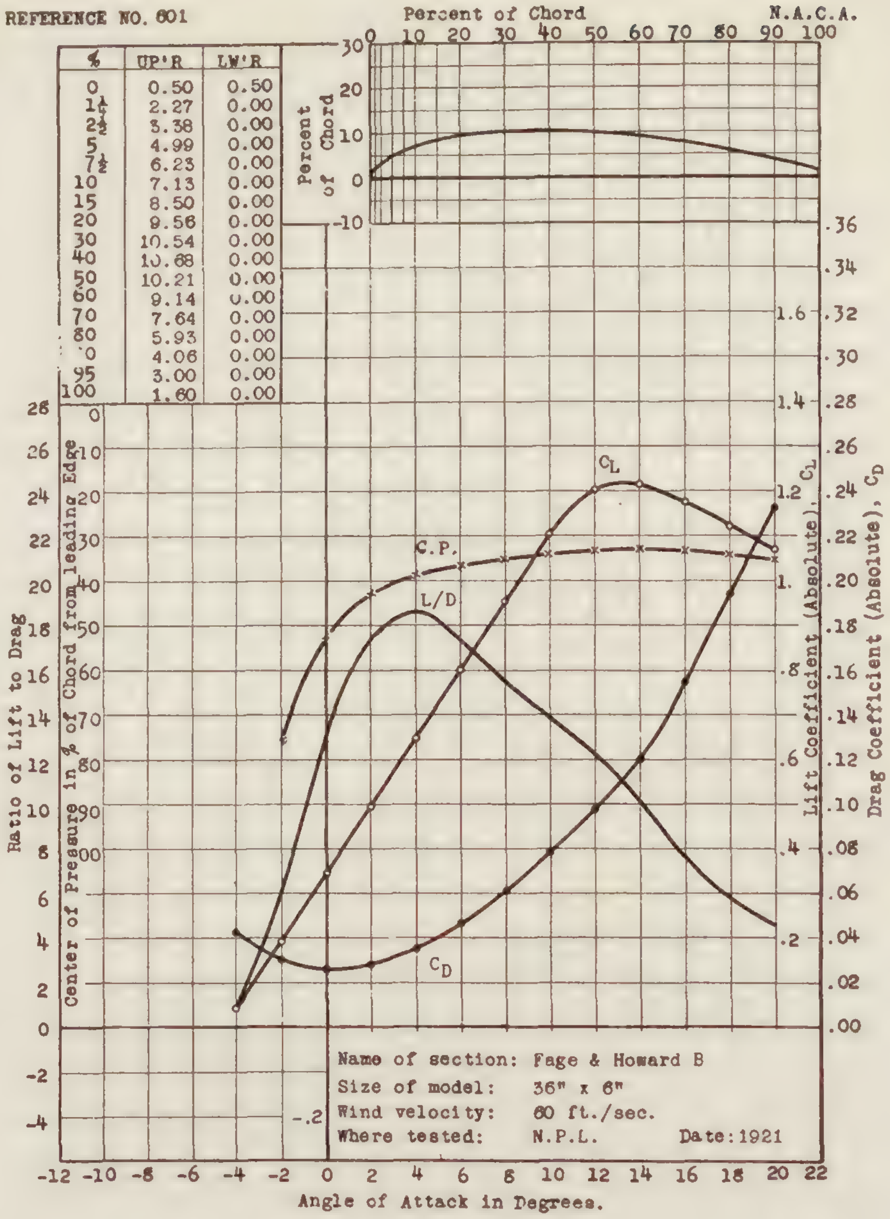
REFERENCE NO. 600



%	UP'R	LW'R
0	1.00	1.00
1¼	2.82	0.00
2½	3.75	0.00
5	4.92	0.00
7½	5.70	0.00
10	6.27	0.00
15	7.24	0.00
20	7.87	0.00
30	8.55	0.00
40	8.67	0.00
50	8.30	0.00
60	7.53	0.00
70	6.46	0.00
80	5.12	0.00
90	3.45	0.00
95	2.38	0.00
100	1.30	0.00

Name of section: Fage & Howard A
Size of model: 36" x 6"
Wind velocity: 60 ft./sec.
Where tested: N.P.L. Date: 1921

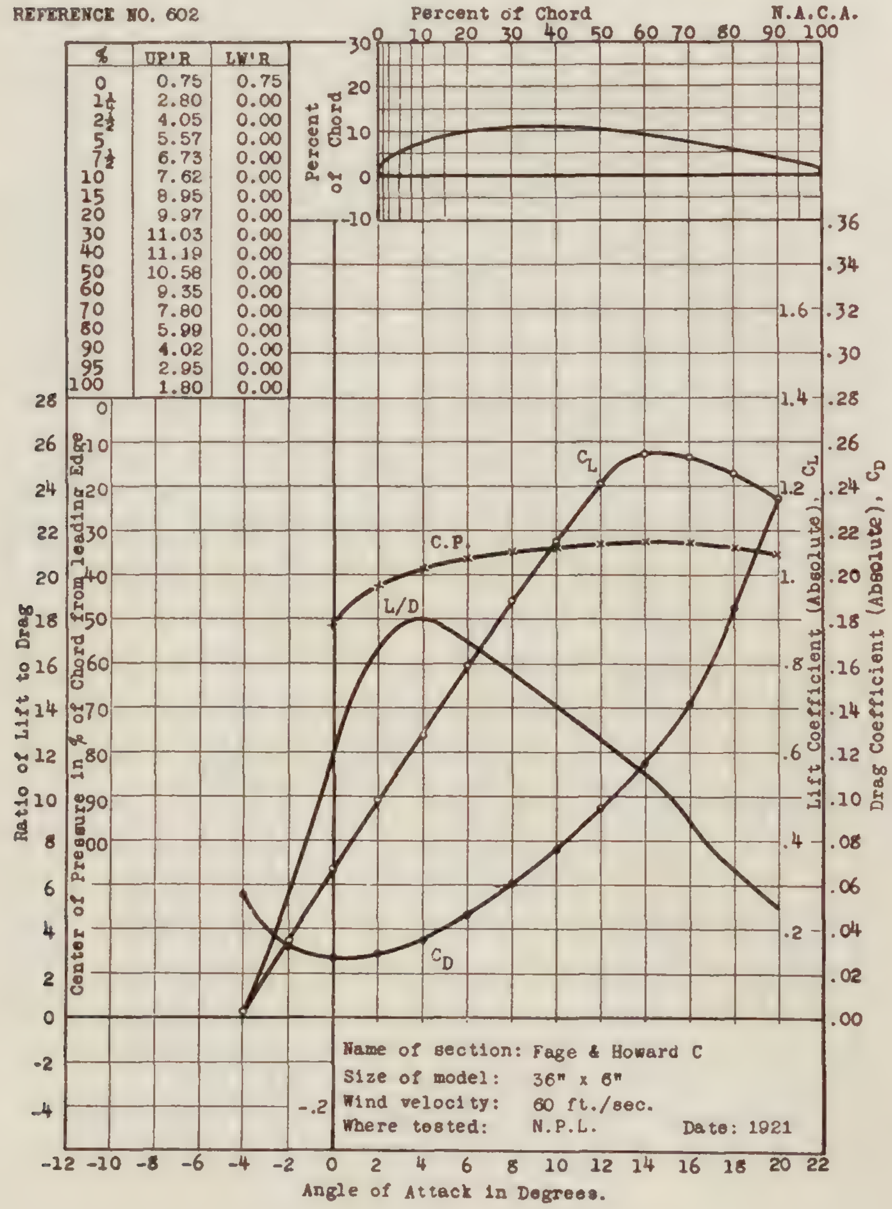
REFERENCE NO. 601



%	UP'R	LW'R
0	0.50	0.50
1¼	2.27	0.00
2½	3.38	0.00
5	4.99	0.00
7½	6.23	0.00
10	7.13	0.00
15	8.50	0.00
20	9.56	0.00
30	10.54	0.00
40	10.68	0.00
50	10.21	0.00
60	9.14	0.00
70	7.64	0.00
80	5.93	0.00
90	4.06	0.00
95	3.00	0.00
100	1.60	0.00

Name of section: Fage & Howard B
Size of model: 36" x 6"
Wind velocity: 60 ft./sec.
Where tested: N.P.L. Date: 1921

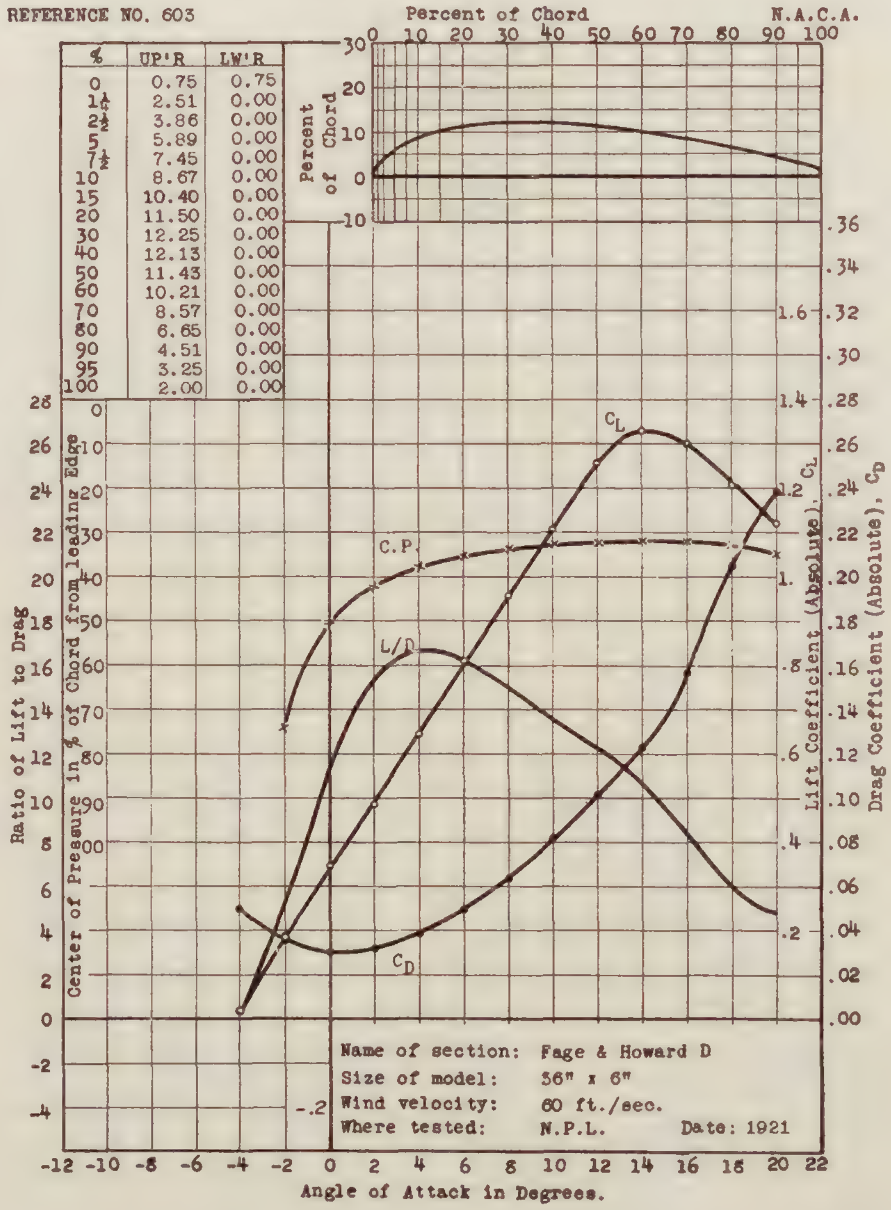
REFERENCE NO. 602



%	UP'R	LW'R
0	0.75	0.75
1¼	2.80	0.00
2½	4.05	0.00
5	5.57	0.00
7½	6.73	0.00
10	7.62	0.00
15	8.95	0.00
20	9.97	0.00
30	11.03	0.00
40	11.19	0.00
50	10.58	0.00
60	9.35	0.00
70	7.80	0.00
80	5.99	0.00
90	4.02	0.00
95	2.95	0.00
100	1.80	0.00

Name of section: Fage & Howard C
Size of model: 36" x 6"
Wind velocity: 60 ft./sec.
Where tested: N.P.L. Date: 1921

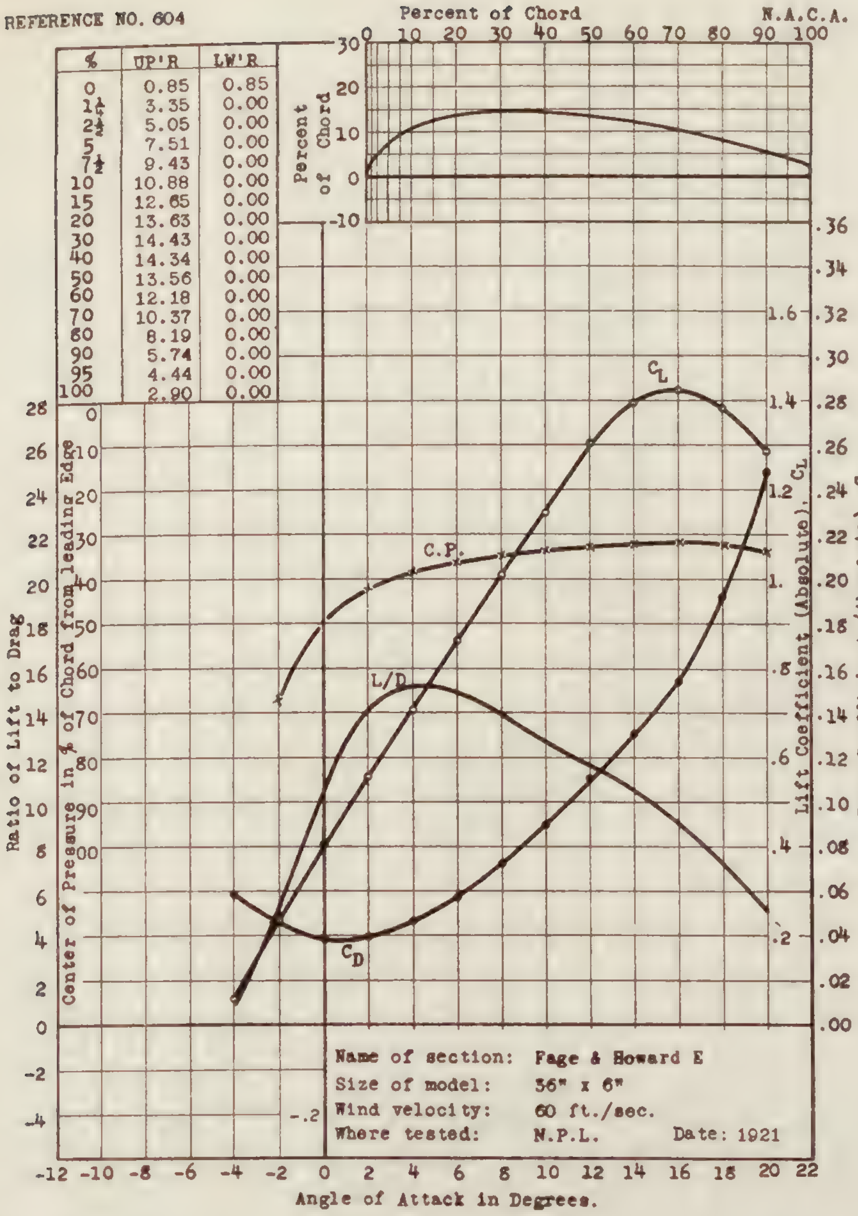
REFERENCE NO. 603



%	UP'R	LW'R
0	0.75	0.75
1¼	2.51	0.00
2½	3.86	0.00
5	5.89	0.00
7½	7.45	0.00
10	8.67	0.00
15	10.40	0.00
20	11.50	0.00
30	12.25	0.00
40	12.13	0.00
50	11.43	0.00
60	10.21	0.00
70	8.57	0.00
80	6.65	0.00
90	4.51	0.00
95	3.25	0.00
100	2.00	0.00

Name of section: Fage & Howard D
Size of model: 36" x 6"
Wind velocity: 60 ft./sec.
Where tested: N.P.L. Date: 1921

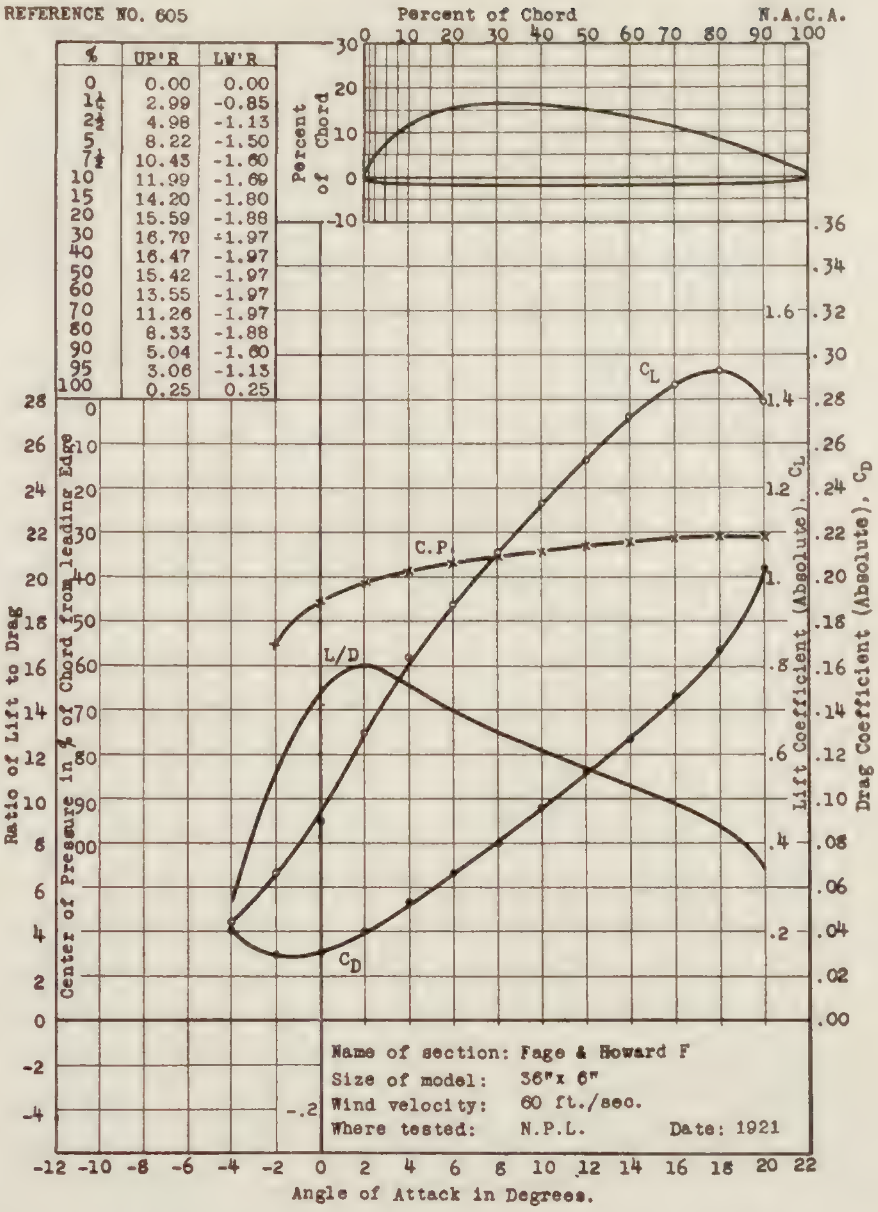
REFERENCE NO. 604



%	UP'R	LW'R
0	0.85	0.85
1¼	3.35	0.00
2½	5.05	0.00
5	7.51	0.00
7½	9.43	0.00
10	10.88	0.00
15	12.65	0.00
20	13.63	0.00
30	14.43	0.00
40	14.34	0.00
50	13.56	0.00
60	12.18	0.00
70	10.37	0.00
80	8.19	0.00
90	5.74	0.00
95	4.44	0.00
100	2.90	0.00

Name of section: Page & Howard E
Size of model: 36" x 6"
Wind velocity: 60 ft./sec.
Where tested: N.P.L. Date: 1921

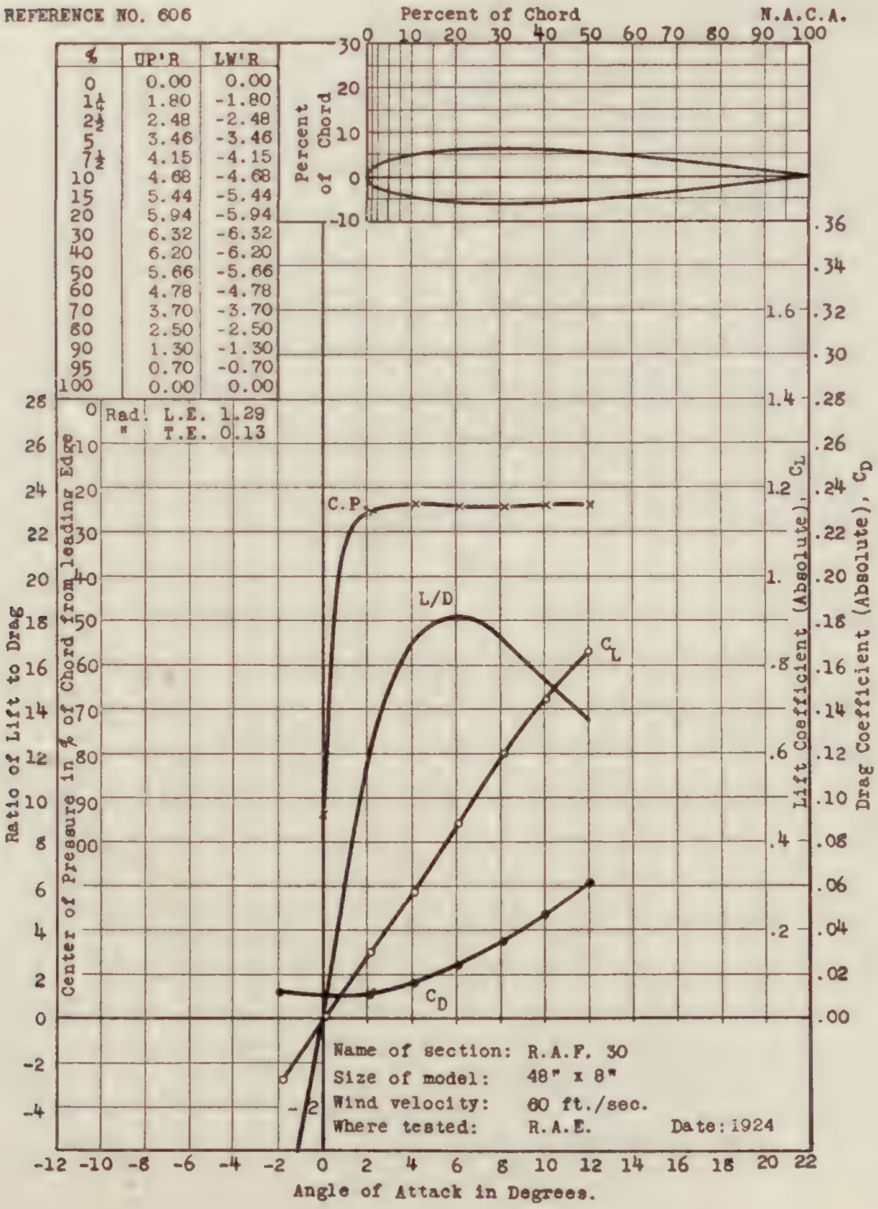
REFERENCE NO. 605



%	UP'R	LW'R
0	0.00	0.00
1¼	2.99	-0.85
2½	4.98	-1.13
5	8.22	-1.50
7½	10.43	-1.60
10	11.99	-1.69
15	14.20	-1.80
20	15.59	-1.88
30	16.79	-1.97
40	16.47	-1.97
50	15.42	-1.97
60	13.55	-1.97
70	11.26	-1.97
80	8.33	-1.88
90	5.04	-1.60
95	3.06	-1.13
100	0.25	0.25

Name of section: Page & Howard F
Size of model: 36"x 6"
Wind velocity: 60 ft./sec.
Where tested: N.P.L. Date: 1921

REFERENCE NO. 606

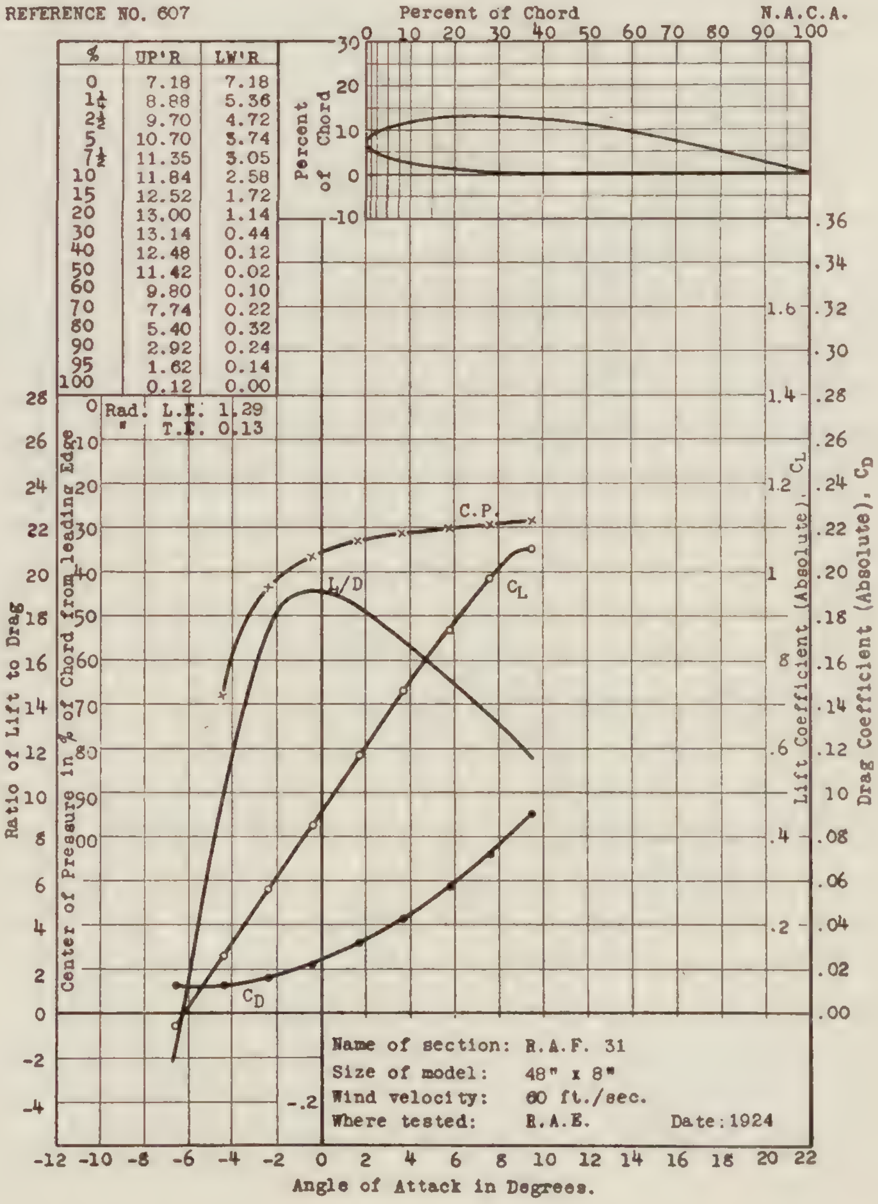


%	UP'R	LW'R
0	0.00	0.00
1¼	1.80	-1.80
2½	2.48	-2.48
5	3.46	-3.46
7½	4.15	-4.15
10	4.68	-4.68
15	5.44	-5.44
20	5.94	-5.94
30	6.32	-6.32
40	6.20	-6.20
50	5.66	-5.66
60	4.78	-4.78
70	3.70	-3.70
80	2.50	-2.50
90	1.30	-1.30
95	0.70	-0.70
100	0.00	0.00

Rad. L.E. 1.29
" T.E. 0.13

Name of section: R.A.F. 30
Size of model: 48" x 8"
Wind velocity: 60 ft./sec.
Where tested: R.A.E. Date: 1924

REFERENCE NO. 607

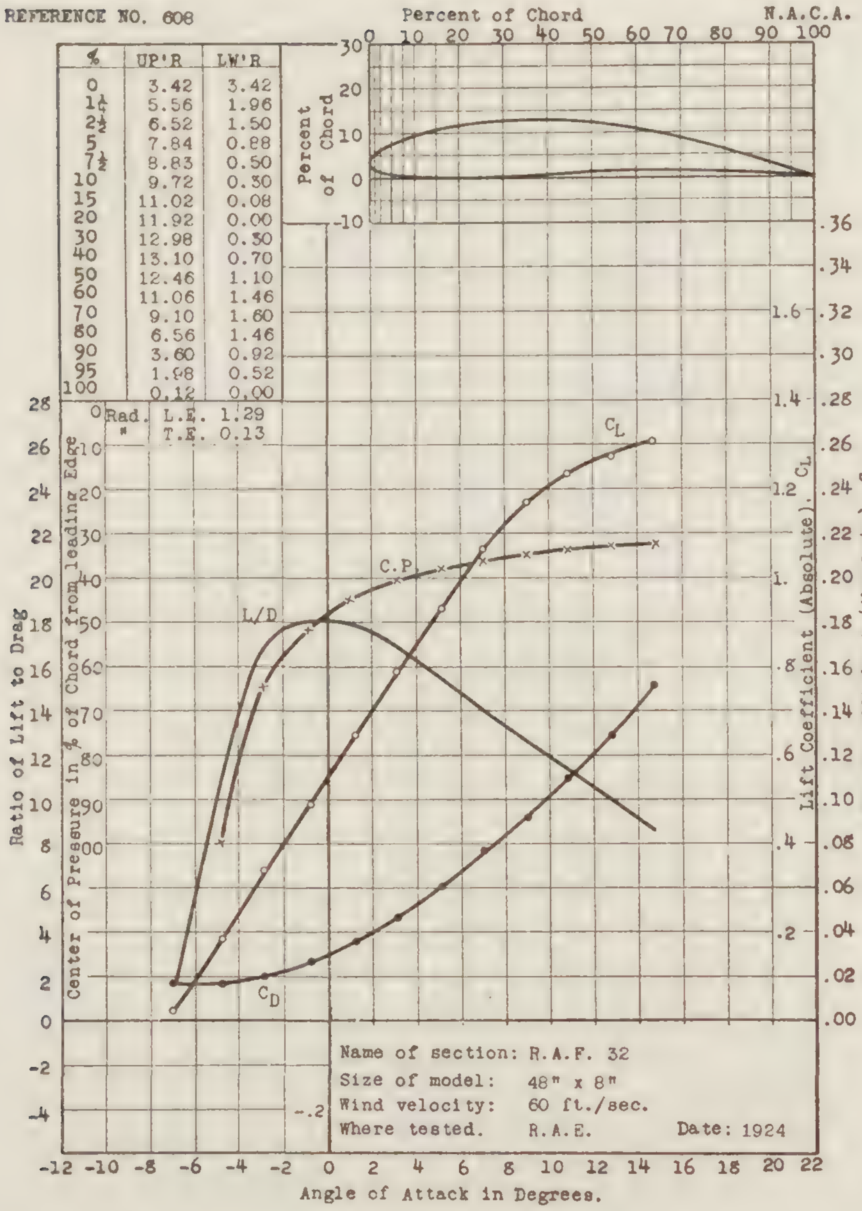


%	UP'R	LW'R
0	7.18	7.18
1¼	8.88	5.36
2½	9.70	4.72
5	10.70	3.74
7½	11.35	3.05
10	11.84	2.58
15	12.52	1.72
20	13.00	1.14
30	13.14	0.44
40	12.48	0.12
50	11.42	0.02
60	9.80	0.10
70	7.74	0.22
80	5.40	0.32
90	2.92	0.24
95	1.62	0.14
100	0.12	0.00

Rad. L.E. 1.29
" T.E. 0.13

Name of section: R.A.F. 31
Size of model: 48" x 8"
Wind velocity: 60 ft./sec.
Where tested: R.A.E. Date: 1924

REFERENCE NO. 608

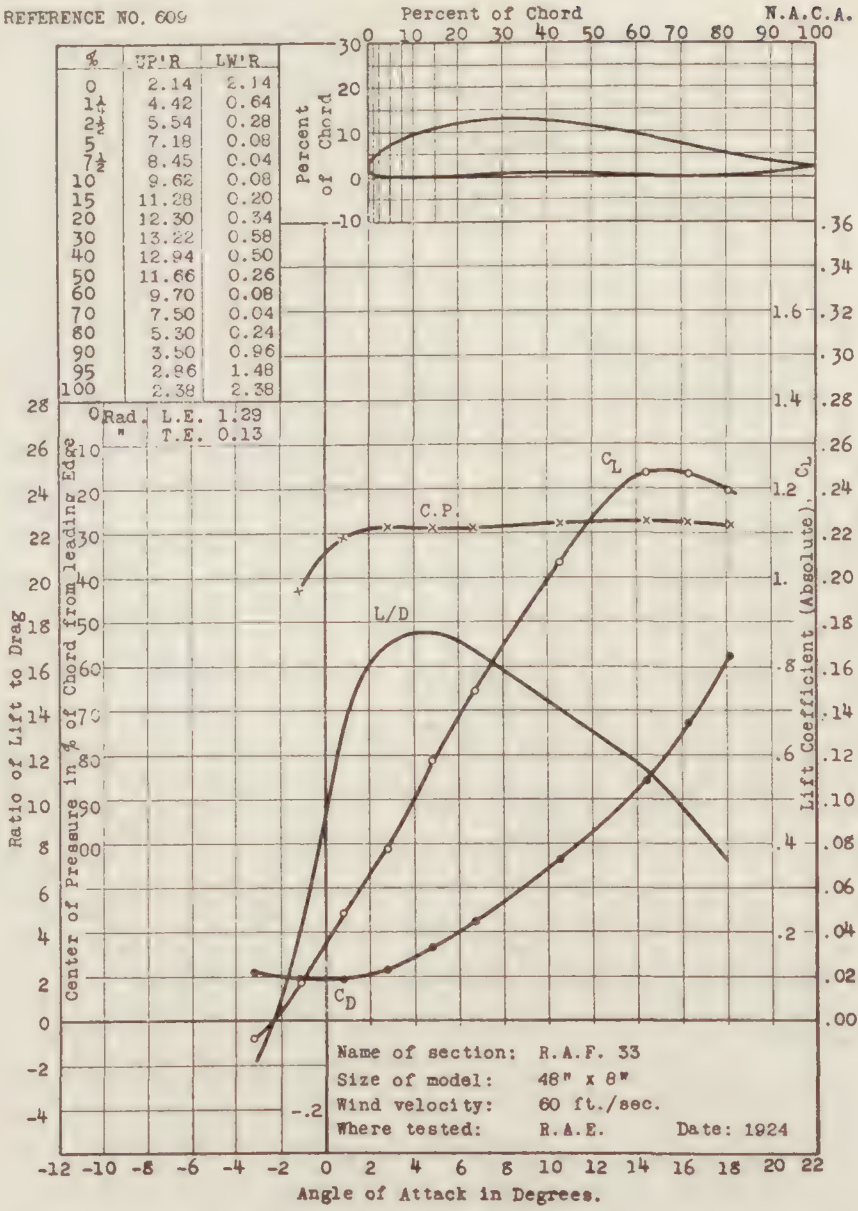


%	UP'R	LW'R
0	3.42	3.42
1¼	5.56	1.96
2½	6.52	1.50
5	7.84	0.88
7½	8.83	0.50
10	9.72	0.30
15	11.02	0.08
20	11.92	0.00
30	12.98	0.30
40	13.10	0.70
50	12.46	1.10
60	11.06	1.46
70	9.10	1.60
80	6.56	1.46
90	3.60	0.92
95	1.98	0.52
100	0.12	0.00

Rad. L.E. 1.29
" T.E. 0.13

Name of section: R.A.F. 32
Size of model: 48" x 8"
Wind velocity: 60 ft./sec.
Where tested. R.A.E. Date: 1924

REFERENCE NO. 609

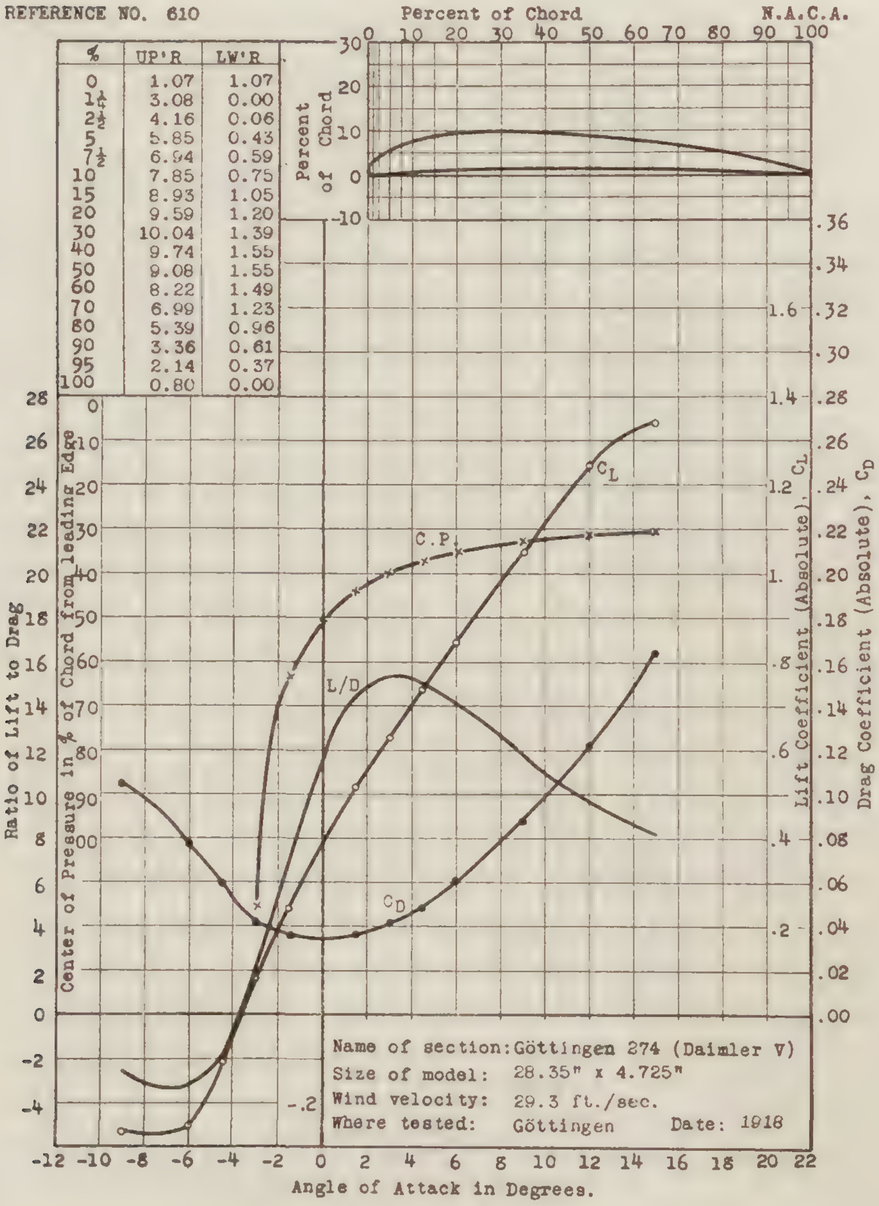


%	UP'R	LW'R
0	2.14	2.14
1¼	4.42	0.64
2½	5.54	0.28
5	7.18	0.08
7½	8.45	0.04
10	9.62	0.08
15	11.28	0.20
20	12.30	0.34
30	13.22	0.58
40	12.94	0.50
50	11.66	0.26
60	9.70	0.08
70	7.50	0.04
80	5.30	0.24
90	3.50	0.96
95	2.86	1.48
100	2.38	2.38

Rad. L.E. 1.29
" T.E. 0.13

Name of section: R.A.F. 33
Size of model: 48" x 8"
Wind velocity: 60 ft./sec.
Where tested: R.A.E. Date: 1924

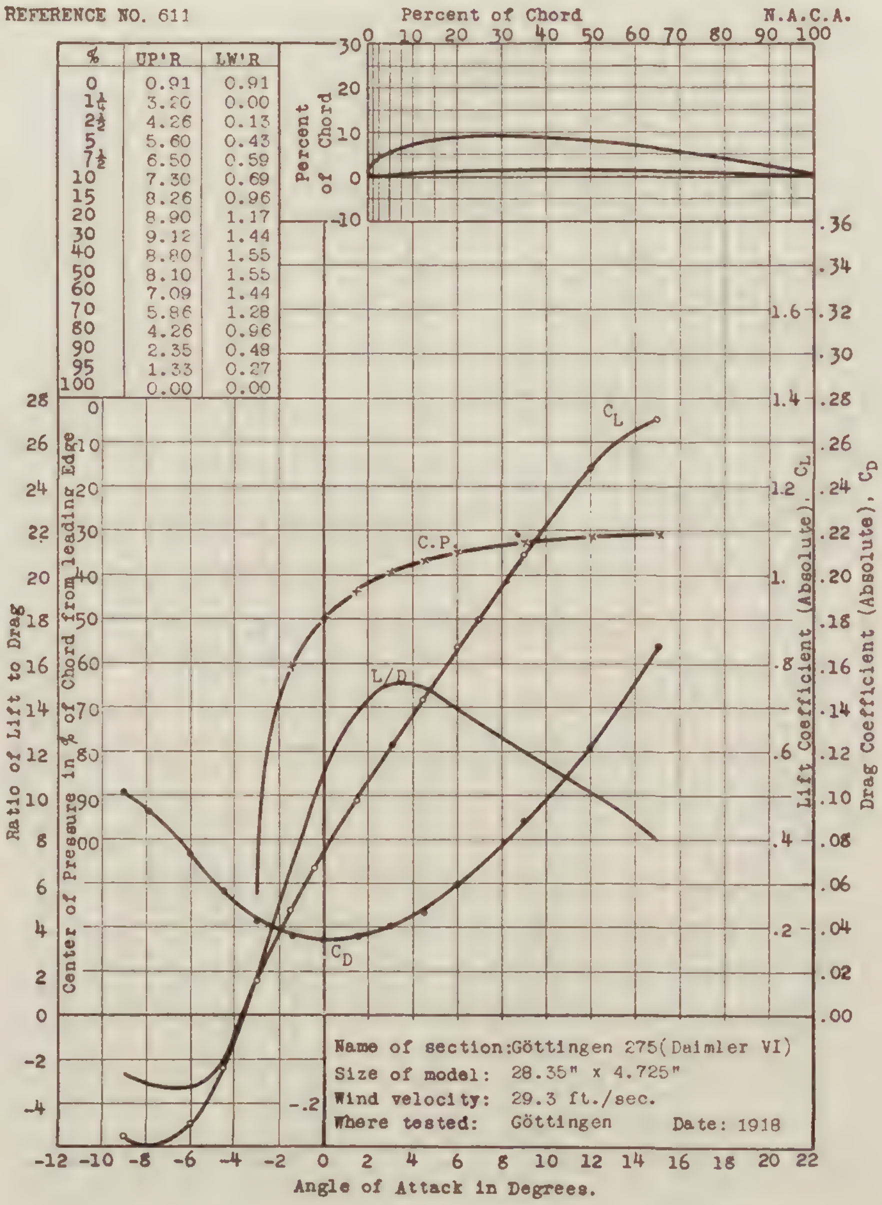
REFERENCE NO. 610



%	UP'R	LW'R
0	1.07	1.07
1¼	3.08	0.00
2½	4.16	0.06
5	5.85	0.43
7½	6.94	0.59
10	7.85	0.75
15	8.93	1.05
20	9.59	1.20
30	10.04	1.39
40	9.74	1.55
50	9.08	1.55
60	8.22	1.49
70	6.99	1.23
80	5.39	0.96
90	3.36	0.61
95	2.14	0.37
100	0.80	0.00

Name of section: Göttingen 274 (Daimler V)
Size of model: 28.35" x 4.725"
Wind velocity: 29.3 ft./sec.
Where tested: Göttingen Date: 1918

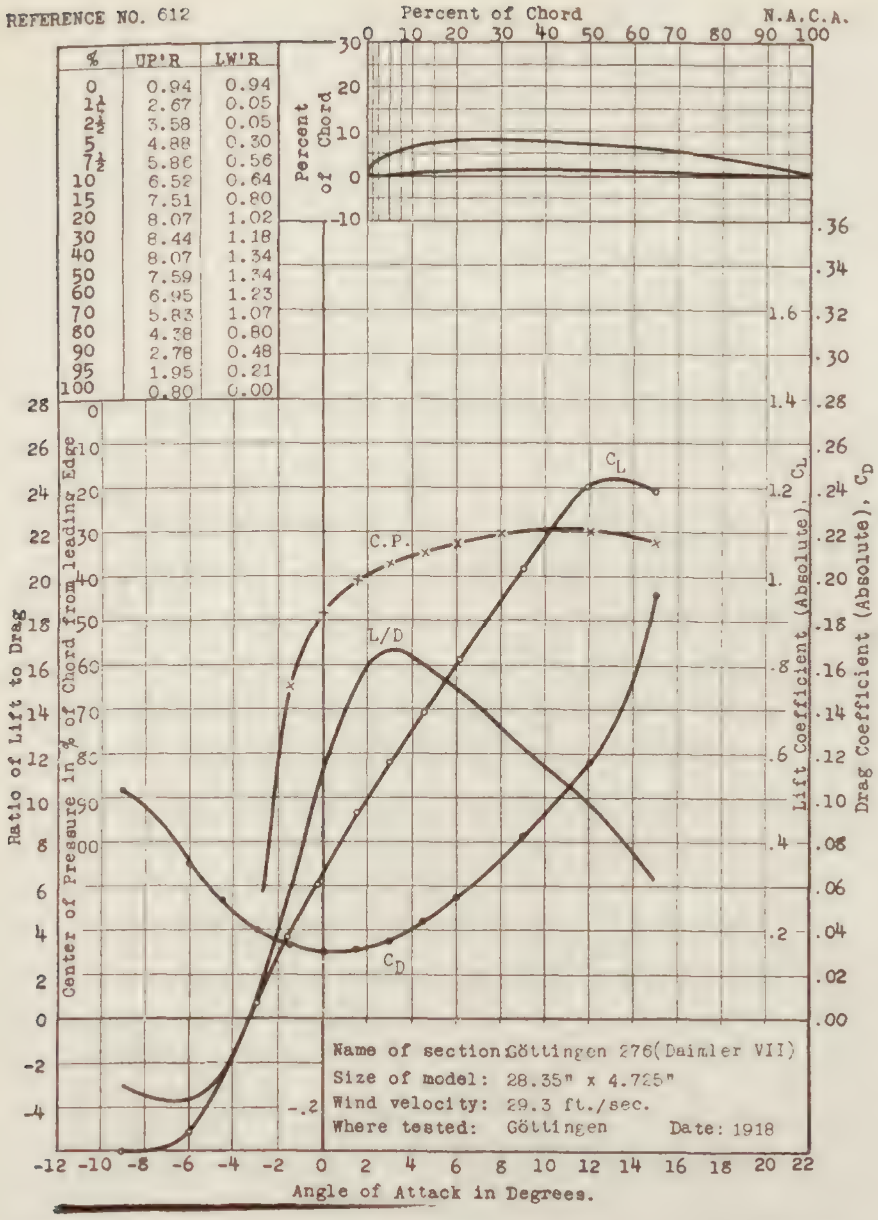
REFERENCE NO. 611



%	UP'R	LW'R
0	0.91	0.91
1¼	3.20	0.00
2½	4.26	0.13
5	5.60	0.43
7½	6.50	0.59
10	7.30	0.69
15	8.26	0.96
20	8.90	1.17
30	9.12	1.44
40	8.80	1.55
50	8.10	1.55
60	7.09	1.44
70	5.86	1.28
80	4.26	0.96
90	2.35	0.48
95	1.33	0.27
100	0.00	0.00

Name of section: Göttingen 275 (Daimler VI)
Size of model: 28.35" x 4.725"
Wind velocity: 29.3 ft./sec.
Where tested: Göttingen Date: 1918

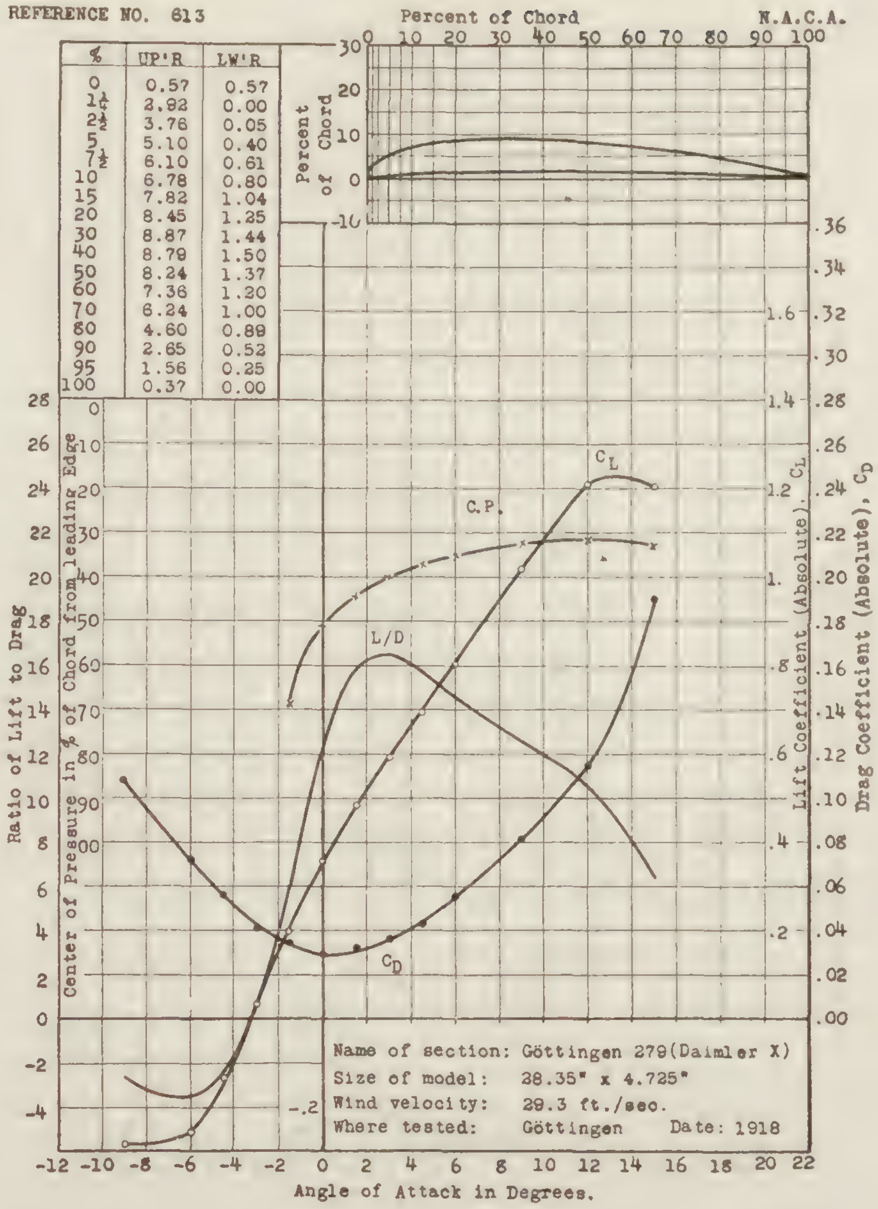
REFERENCE NO. 612



%	UP'R	LW'R
0	0.94	0.94
1¼	2.67	0.05
2½	3.58	0.05
5	4.88	0.30
7½	5.86	0.56
10	6.52	0.64
15	7.51	0.80
20	8.07	1.02
30	8.44	1.18
40	8.07	1.34
50	7.59	1.34
60	6.95	1.23
70	5.83	1.07
80	4.38	0.80
90	2.78	0.48
95	1.95	0.21
100	0.80	0.00

Name of section: Göttingen 276(Daimler VII)
Size of model: 28.35" x 4.725"
Wind velocity: 29.3 ft./sec.
Where tested: Göttingen Date: 1918

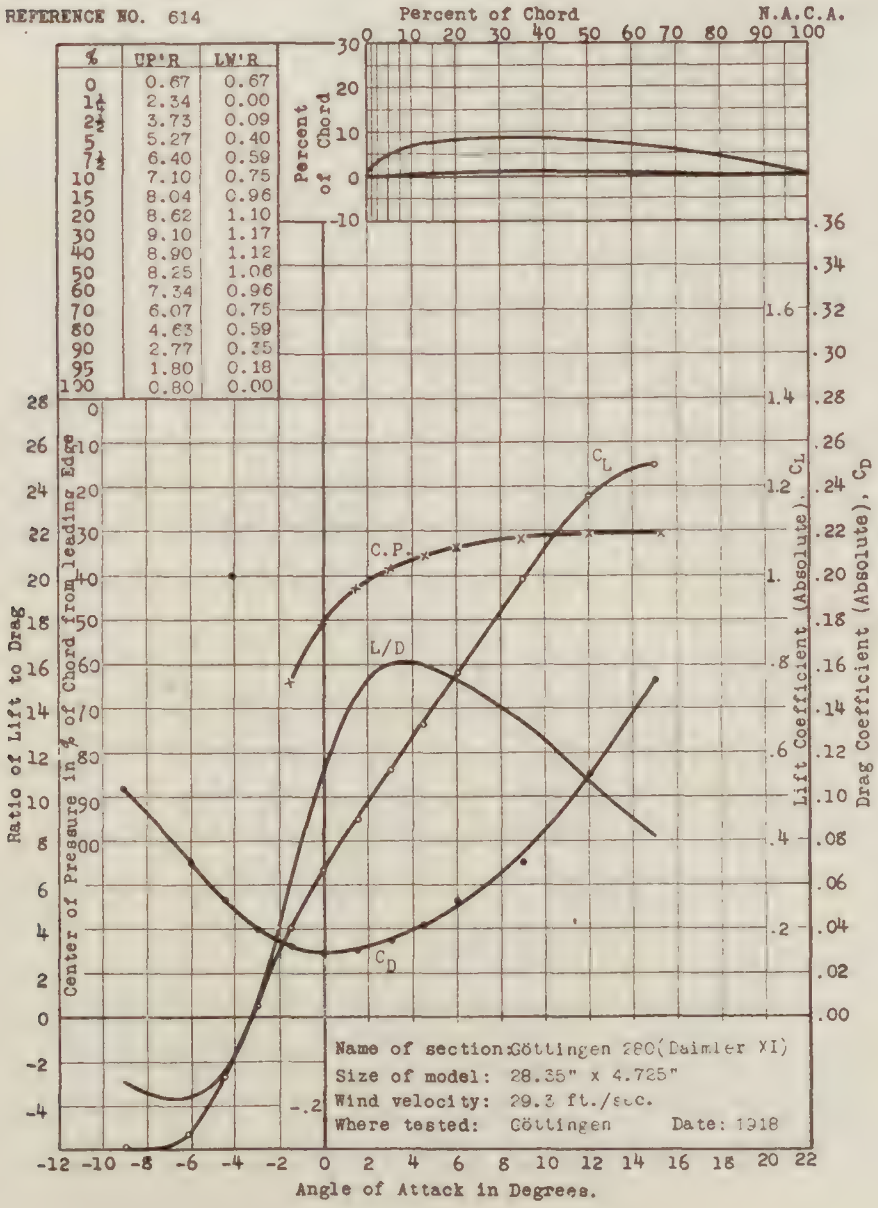
REFERENCE NO. 613



%	UP'R	LW'R
0	0.57	0.57
1¼	2.82	0.00
2½	3.76	0.05
5	5.10	0.40
7½	6.10	0.61
10	6.78	0.80
15	7.82	1.04
20	8.45	1.25
30	8.87	1.44
40	8.79	1.50
50	8.24	1.37
60	7.36	1.20
70	6.24	1.00
80	4.60	0.88
90	2.65	0.52
95	1.56	0.25
100	0.37	0.00

Name of section: Göttingen 279(Daimler X)
Size of model: 28.35" x 4.725"
Wind velocity: 29.3 ft./sec.
Where tested: Göttingen Date: 1918

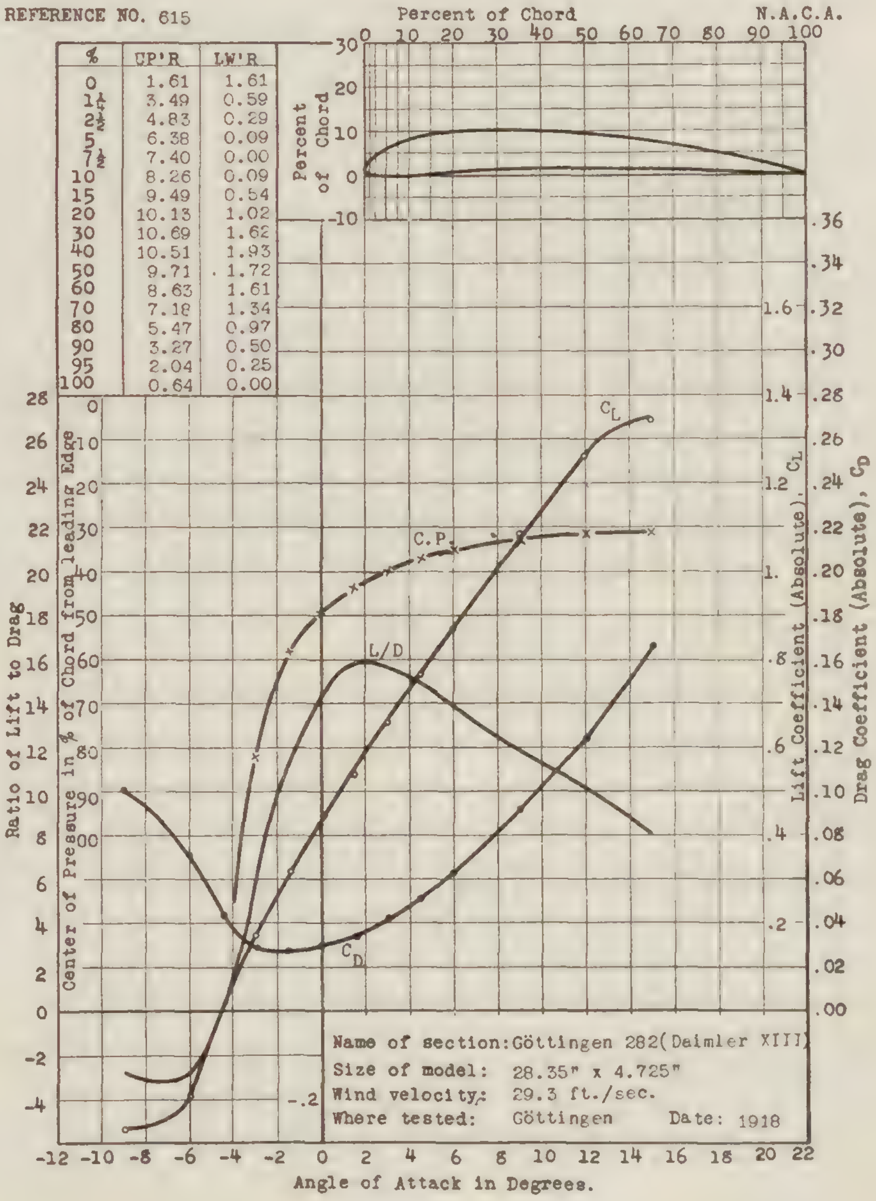
REFERENCE NO. 614



%	UP'R	LW'R
0	0.67	0.67
1¼	2.34	0.00
2½	3.73	0.09
5	5.27	0.40
7½	6.40	0.59
10	7.10	0.75
15	8.04	0.96
20	8.62	1.10
30	9.10	1.17
40	8.90	1.12
50	8.25	1.06
60	7.34	0.96
70	6.07	0.75
80	4.63	0.59
90	2.77	0.35
95	1.80	0.18
100	0.80	0.00

Name of section: Göttingen 280(Daimler XI)
Size of model: 28.35" x 4.725"
Wind velocity: 29.3 ft./sec.
Where tested: Göttingen Date: 1918

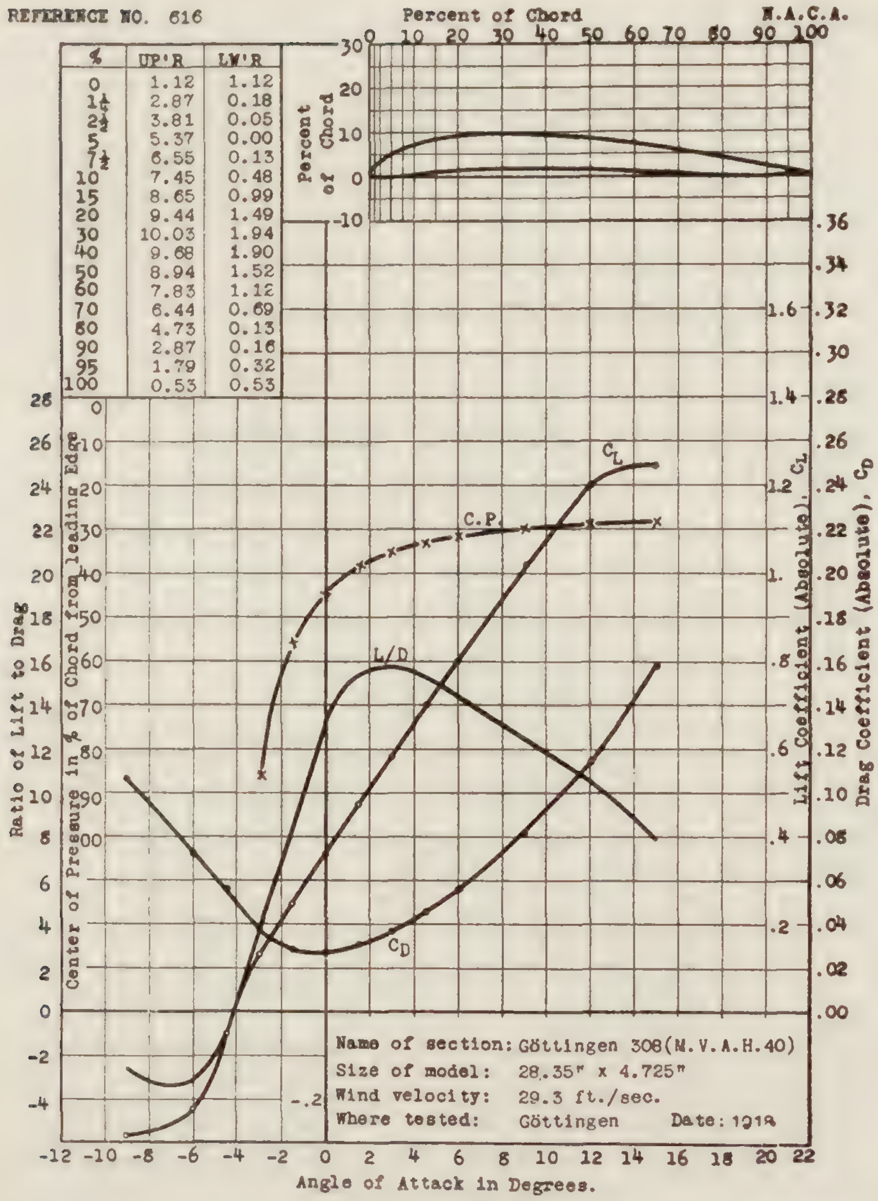
REFERENCE NO. 615



%	UP'R	LW'R
0	1.61	1.61
1¼	3.49	0.59
2½	4.83	0.29
5	6.38	0.09
7½	7.40	0.00
10	8.26	0.09
15	9.49	0.54
20	10.13	1.02
30	10.69	1.62
40	10.51	1.93
50	9.71	1.72
60	8.63	1.61
70	7.18	1.34
80	5.47	0.97
90	3.27	0.50
95	2.04	0.25
100	0.64	0.00

Name of section: Göttingen 282(Daimler XIII)
Size of model: 28.35" x 4.725"
Wind velocity: 29.3 ft./sec.
Where tested: Göttingen Date: 1918

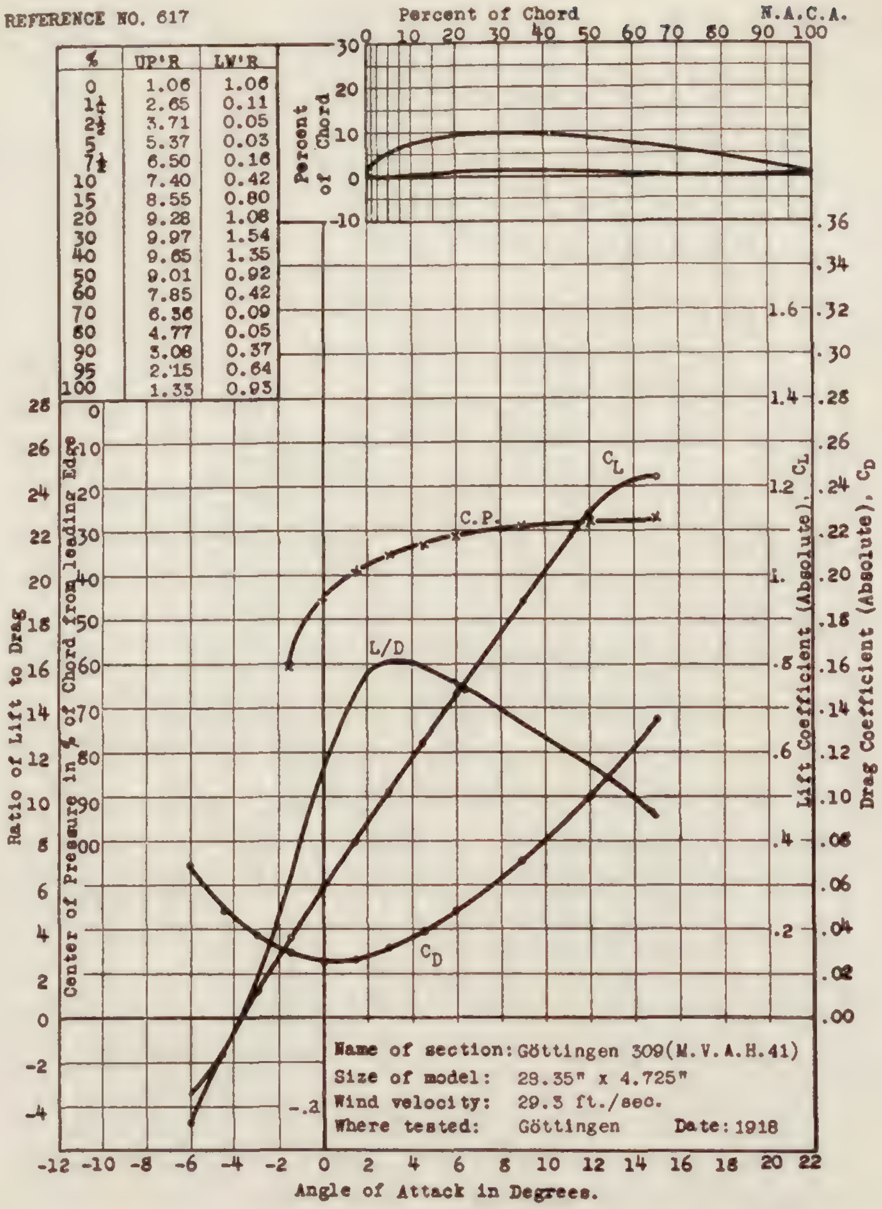
REFERENCE NO. 616



%	UP'R	LW'R
0	1.12	1.12
1¼	2.87	0.18
2½	3.81	0.05
5	5.37	0.00
7½	6.55	0.13
10	7.45	0.48
15	8.65	0.99
20	9.44	1.49
30	10.03	1.94
40	9.68	1.90
50	8.94	1.52
60	7.83	1.12
70	6.44	0.69
80	4.73	0.13
90	2.87	0.16
95	1.79	0.32
100	0.53	0.53

Name of section: Göttingen 308(M.V.A.H.40)
Size of model: 28.35" x 4.725"
Wind velocity: 29.3 ft./sec.
Where tested: Göttingen Date: 1918

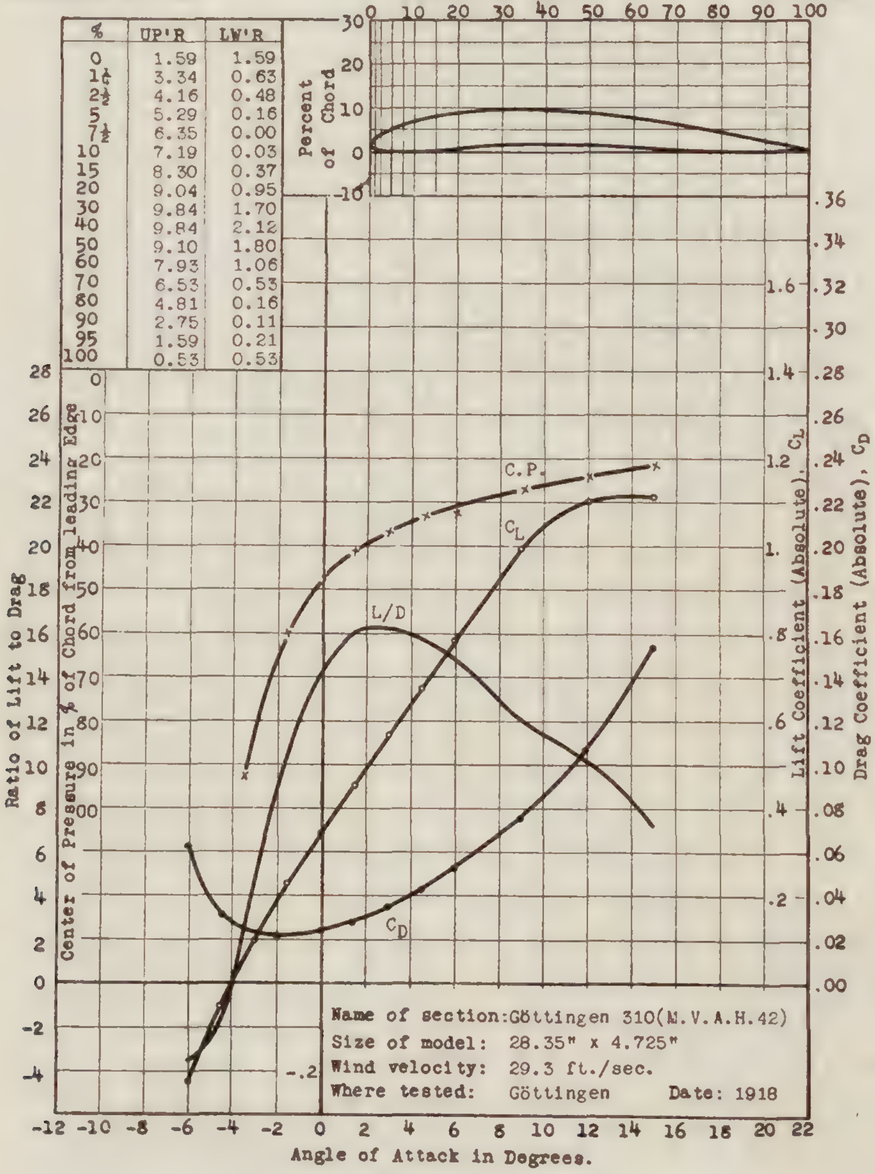
REFERENCE NO. 617



%	UP'R	LW'R
0	1.06	1.06
1¼	2.65	0.11
2½	3.71	0.05
5	5.37	0.03
7½	6.50	0.16
10	7.40	0.42
15	8.55	0.80
20	9.28	1.08
30	9.97	1.54
40	9.65	1.35
50	9.01	0.92
60	7.85	0.42
70	6.36	0.09
80	4.77	0.05
90	3.08	0.37
95	2.15	0.64
100	1.33	0.93

Name of section: Göttingen 309(M.V.A.H.41)
Size of model: 28.35" x 4.725"
Wind velocity: 29.3 ft./sec.
Where tested: Göttingen Date: 1918

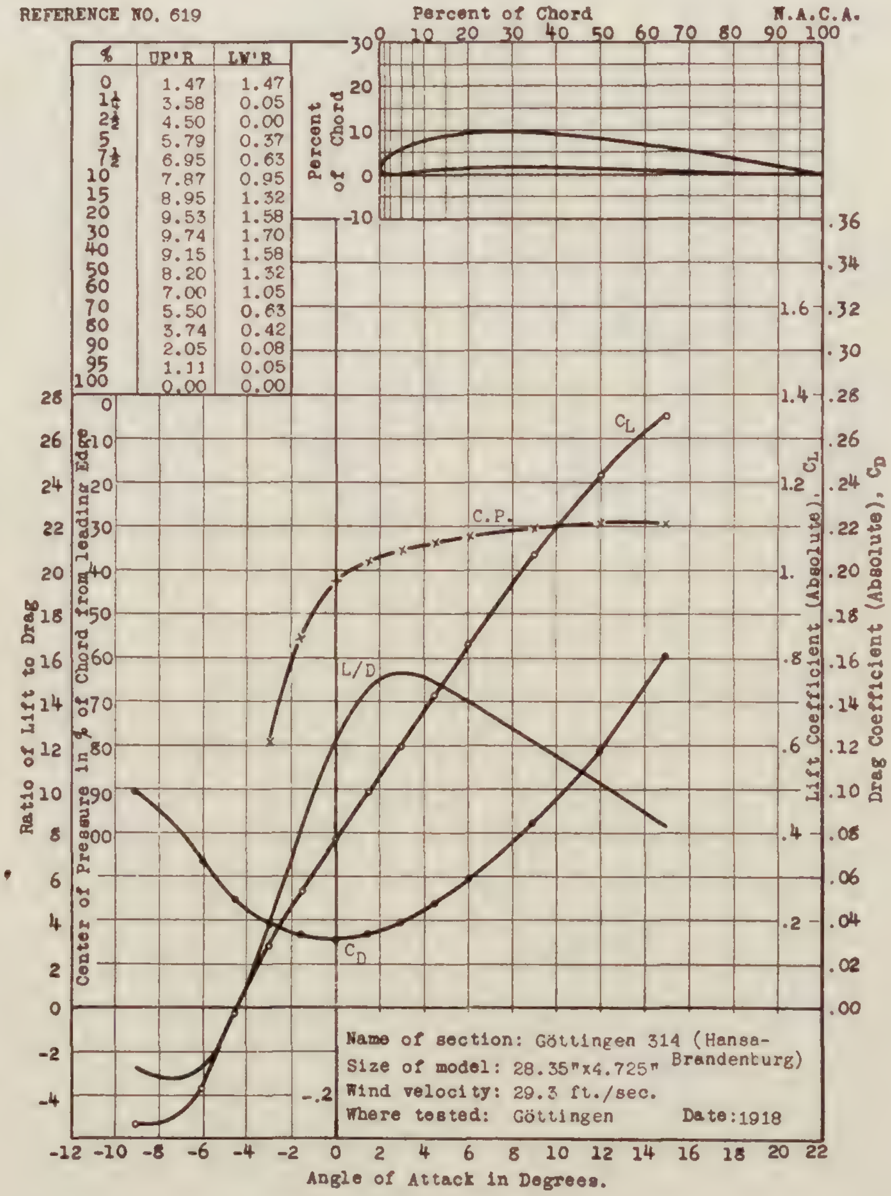
REFERENCE NO. 618



%	UP'R	LW'R
0	1.59	1.59
1¼	3.34	0.63
2½	4.16	0.48
5	5.29	0.16
7½	6.35	0.00
10	7.19	0.03
15	8.30	0.37
20	9.04	0.95
30	9.84	1.70
40	9.84	2.12
50	9.10	1.80
60	7.93	1.06
70	6.53	0.53
80	4.81	0.16
90	2.75	0.11
95	1.59	0.21
100	0.53	0.53

Name of section: Göttingen 310(M.V.A.H.42)
Size of model: 28.35" x 4.725"
Wind velocity: 29.3 ft./sec.
Where tested: Göttingen Date: 1918

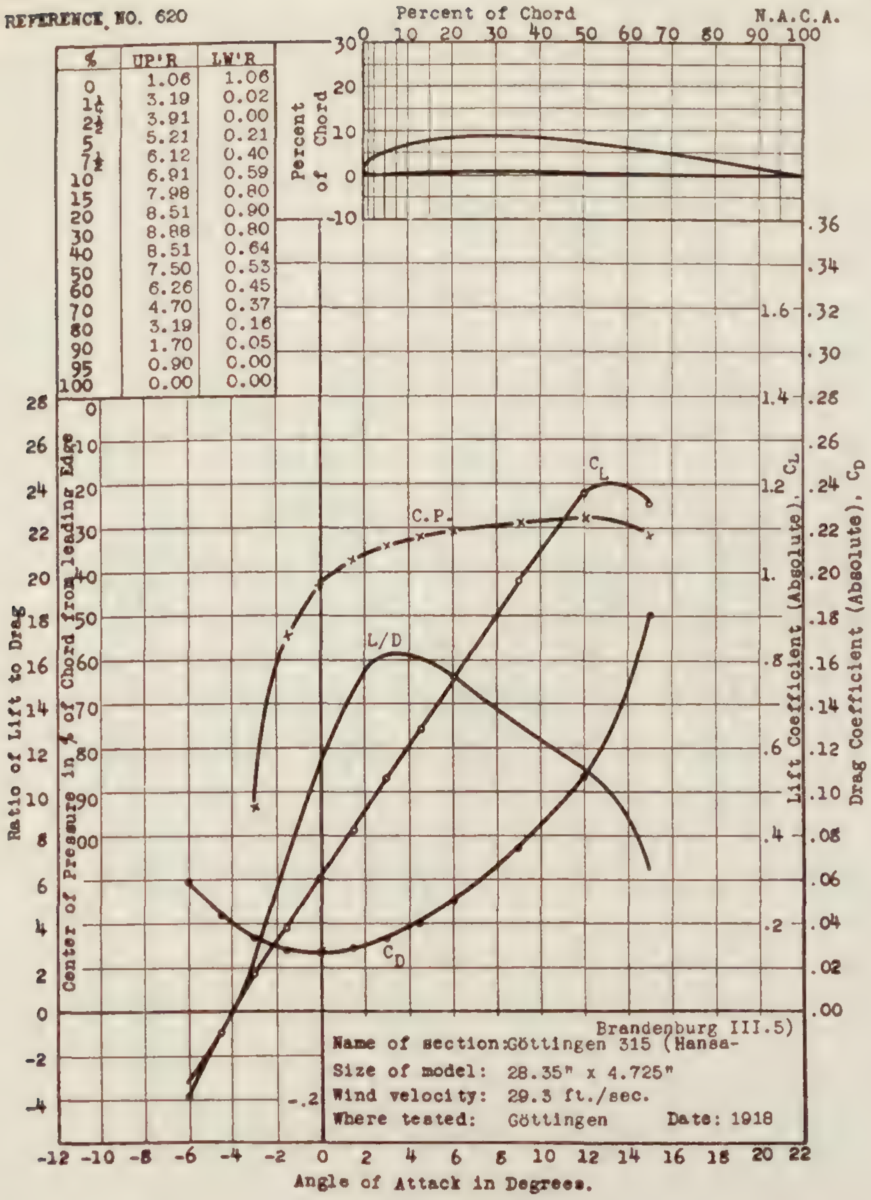
REFERENCE NO. 619



%	UP'R	LW'R
0	1.47	1.47
1¼	3.58	0.05
2½	4.50	0.00
5	5.79	0.37
7½	6.95	0.63
10	7.87	0.95
15	8.95	1.32
20	9.53	1.58
30	9.74	1.70
40	9.15	1.58
50	8.20	1.32
60	7.00	1.05
70	5.50	0.63
80	3.74	0.42
90	2.05	0.08
95	1.11	0.05
100	0.00	0.00

Name of section: Göttingen 314 (Hansa-Brandenburg)
Size of model: 28.35"x4.725"
Wind velocity: 29.3 ft./sec.
Where tested: Göttingen Date: 1918

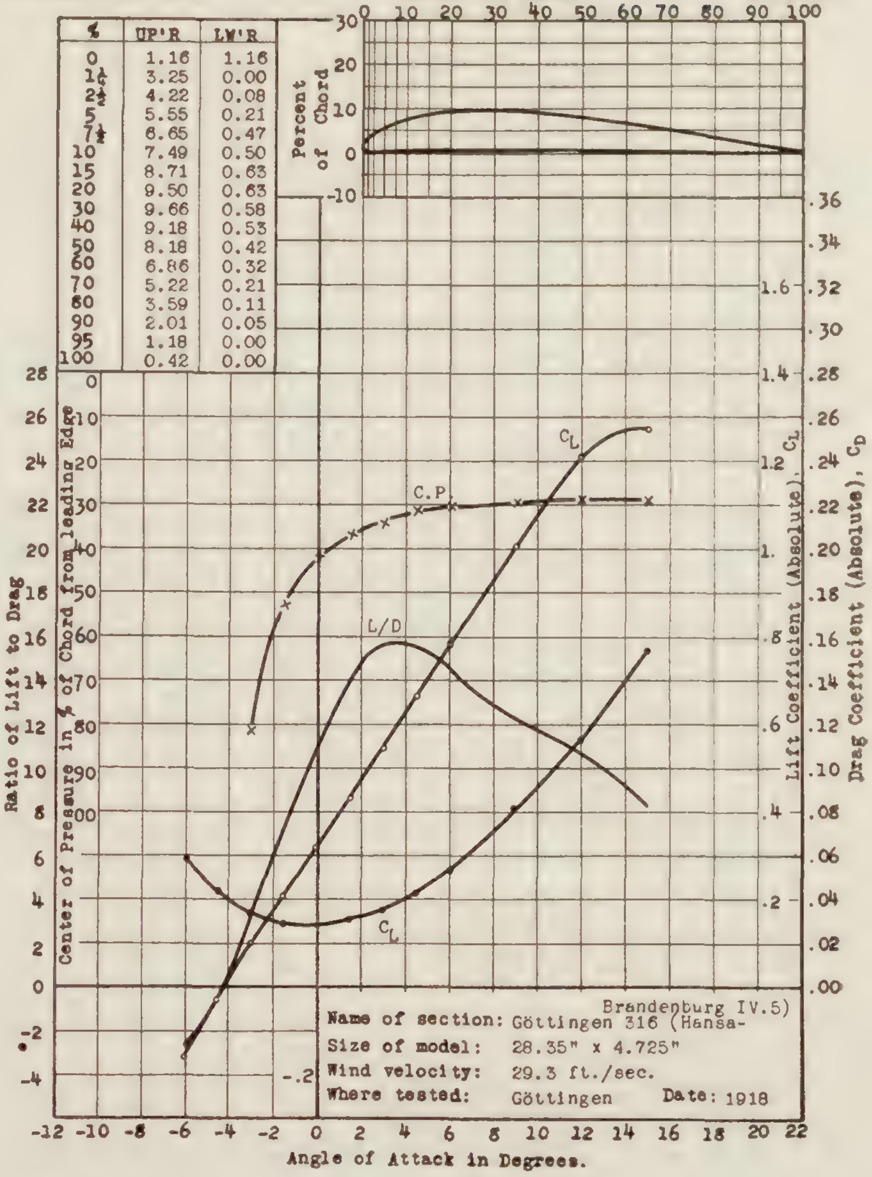
REFERENCE NO. 620



%	UP'R	LW'R
0	1.06	1.06
1¼	3.19	0.02
2½	3.91	0.00
5	5.21	0.21
7½	6.12	0.40
10	6.91	0.59
15	7.98	0.80
20	8.51	0.90
30	8.88	0.80
40	8.51	0.64
50	7.50	0.53
60	6.26	0.45
70	4.70	0.37
80	3.19	0.16
90	1.70	0.05
95	0.90	0.00
100	0.00	0.00

Name of section: Göttingen 315 (Hansa-Brandenburg III.5)
Size of model: 28.35" x 4.725"
Wind velocity: 29.3 ft./sec.
Where tested: Göttingen Date: 1918

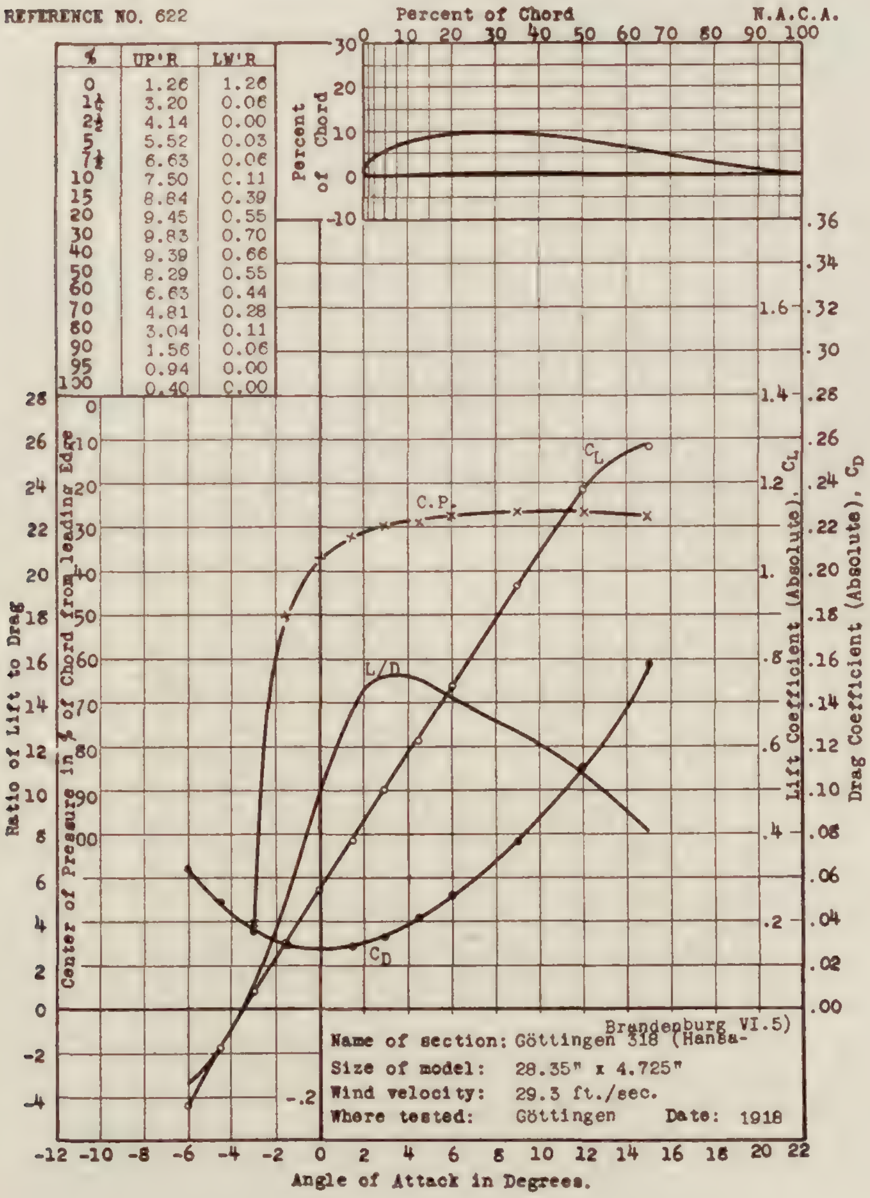
REFERENCE NO. 621



%	UP'R	LW'R
0	1.16	1.16
1¼	3.25	0.00
2½	4.22	0.08
5	5.55	0.21
7½	6.65	0.47
10	7.49	0.50
15	8.71	0.63
20	9.50	0.63
30	9.66	0.58
40	9.18	0.53
50	8.18	0.42
60	6.86	0.32
70	5.22	0.21
80	3.59	0.11
90	2.01	0.05
95	1.18	0.00
100	0.42	0.00

Name of section: Göttingen 316 (Hansa-Brandenburg IV.5)
Size of model: 28.35" x 4.725"
Wind velocity: 29.3 ft./sec.
Where tested: Göttingen Date: 1918

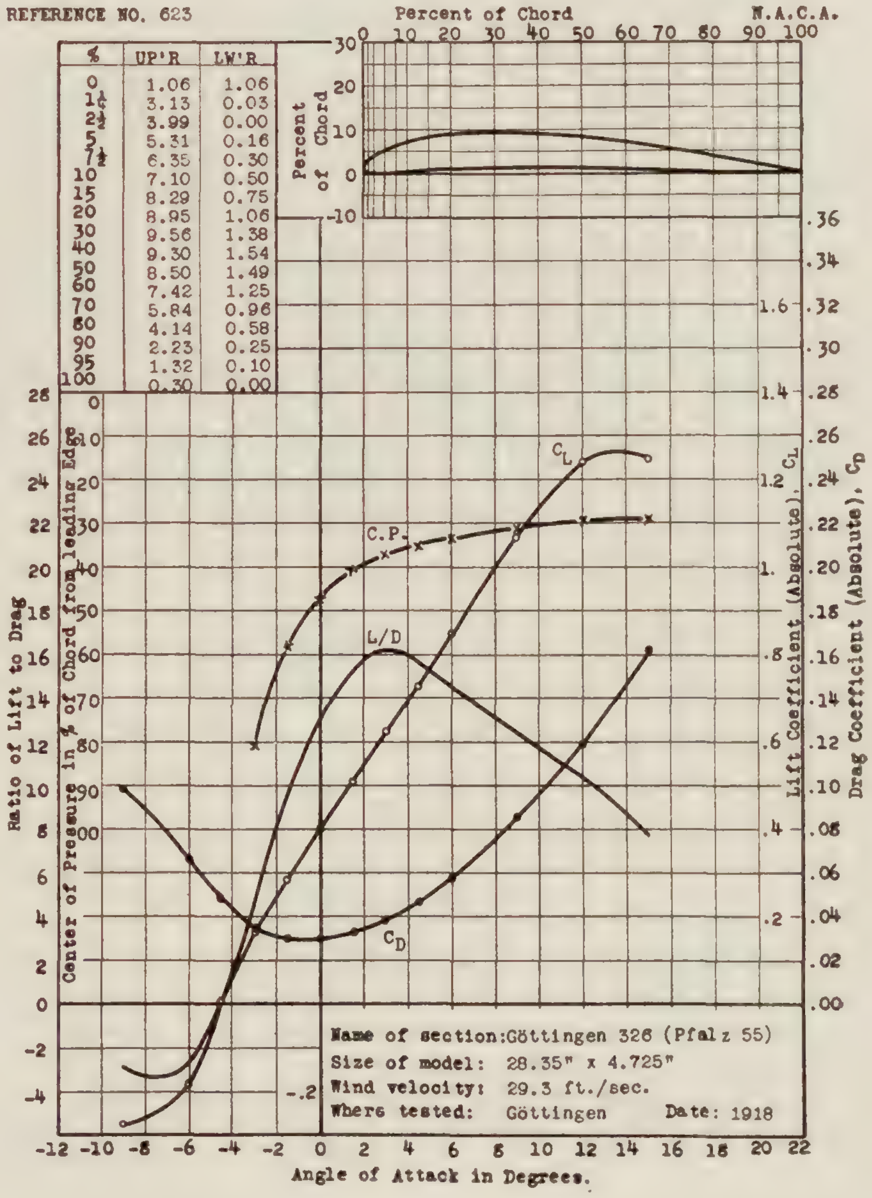
REFERENCE NO. 622



%	UP'R	LW'R
0	1.26	1.26
1¼	3.20	0.06
2½	4.14	0.00
5	5.52	0.03
7½	6.63	0.06
10	7.50	C.11
15	8.84	0.39
20	9.45	0.55
30	9.83	0.70
40	9.39	0.66
50	8.29	0.55
60	6.63	0.44
70	4.81	0.28
80	3.04	0.11
90	1.56	0.06
95	0.94	0.00
100	0.40	C.00

Name of section: Göttingen 318 (Hansa-Brandenburg VI.5)
Size of model: 28.35" x 4.725"
Wind velocity: 29.3 ft./sec.
Where tested: Göttingen Date: 1918

REFERENCE NO. 623



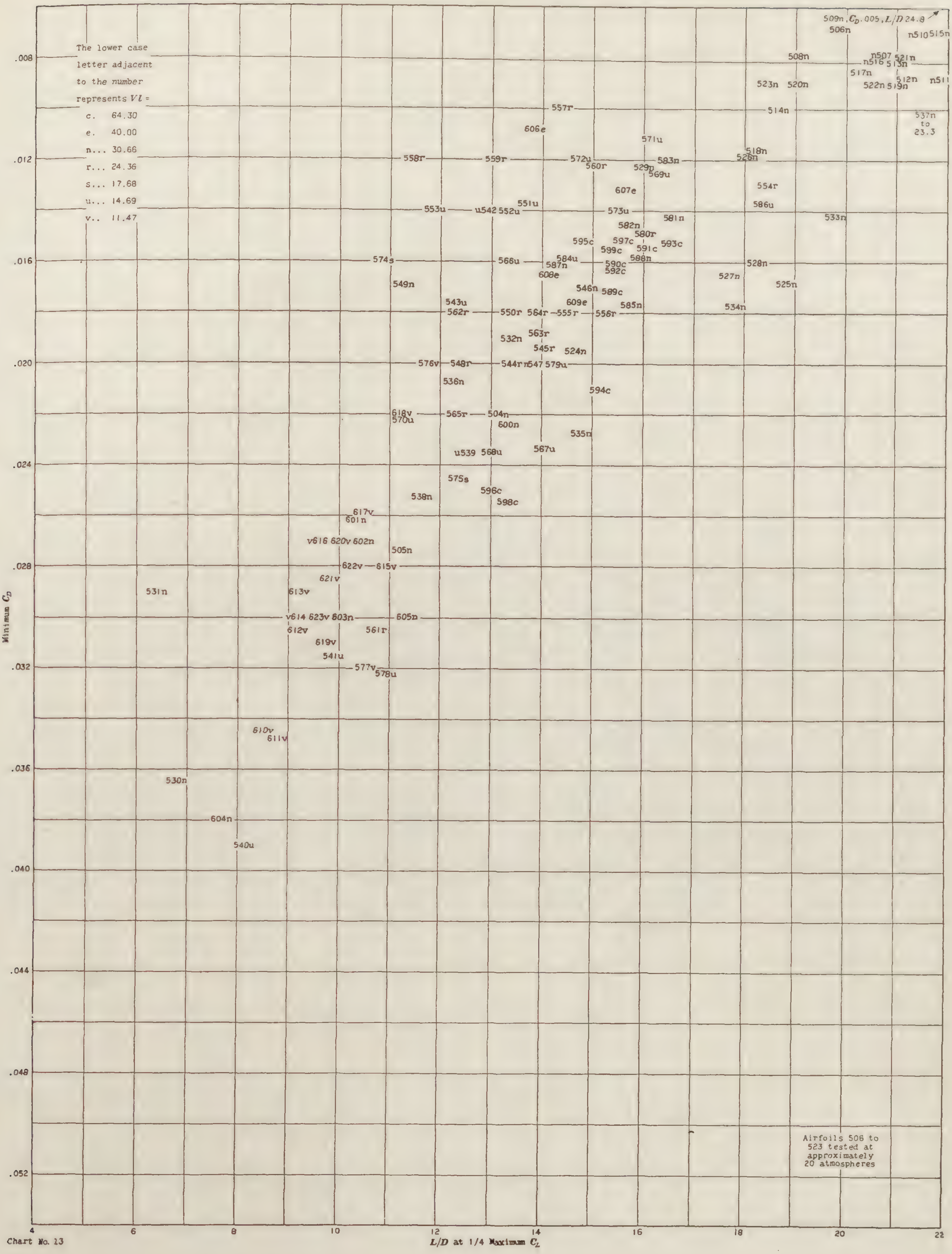
%	UP'R	LW'R
0	1.06	1.06
1¼	3.13	0.03
2½	3.99	0.00
5	5.31	0.16
7½	6.35	0.30
10	7.10	0.50
15	8.29	0.75
20	8.95	1.06
30	9.56	1.38
40	9.30	1.54
50	8.50	1.49
60	7.42	1.25
70	5.84	0.96
80	4.14	0.58
90	2.23	0.25
95	1.32	0.10
100	0.30	0.00

Name of section: Göttingen 326 (Pfalz 55)
Size of model: 28.35" x 4.725"
Wind velocity: 29.3 ft./sec.
Where tested: Göttingen Date: 1918

TABLE OF ORDINATES NOT GIVEN ON INDIVIDUAL CHARACTERISTIC SHEETS

[Ordinates for dotted section at tip where ratio of ordinate to chord differs from that of section at center of span]

Stations in per cent of chord	Ref. 545 Göttingen 387 (tapered)		Ref. 548 Dayton Wright T-1 (tapered)		Ref. 574 R-3		Ref. 575 Glenn Martin 2 (modified)		Ref. 578 U. S. A. 35		Ref. 580 U. S. A. 45	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	2. 55	2. 55	2. 04	2. 04	0. 64	0. 64	1. 39	1. 39	2. 76	2. 76	0. 98	0. 98
1.25	4. 43	1. 07	3. 25	1. 08	1. 39	. 00	3. 35	. 50	5. 14	1. 03	2. 40	. 15
2.50	5. 37	. 70	3. 79	. 79	1. 86	—. 21	4. 49	. 29	6. 09	. 61	3. 12	—. 13
5	6. 70	. 42	4. 60	. 42	2. 67	—. 51	6. 20	. 04	7. 53	. 27	4. 44	—. 42
7.50	7. 53	. 23	5. 25	. 21	3. 22	—. 79	7. 35	. 01	8. 64	. 14	5. 35	—. 65
10	8. 20	. 12	5. 74	. 10	3. 75	—1. 00	8. 41	. 00	9. 46	. 06	6. 12	—. 77
15	9. 15	. 03	6. 46	. 00	4. 40	—1. 35	9. 70	. 06	10. 56	. 00	7. 21	—. 98
20	9. 75	. 00	6. 87	. 05	4. 80	—1. 66	10. 40	. 18	11. 27	. 05	7. 69	—1. 08
30	10. 10	. 03	7. 08	. 21	5. 27	—2. 04	10. 69	1. 00	11. 72	. 16	7. 58	—1. 25
40	9. 73	. 17	6. 91	. 40	5. 27	—2. 04	10. 29	. 85	11. 36	. 28	6. 89	—1. 21
50	8. 83	. 32	6. 45	. 37	5. 00	—2. 00	9. 69	. 71	10. 28	. 38	6. 12	—1. 21
60	7. 59	. 38	5. 66	. 21	4. 46	—1. 87	8. 52	. 29	8. 85	. 43	5. 04	—1. 08
70	6. 00	. 37	4. 66	. 04	3. 68	—1. 46	7. 10	. 04	7. 07	. 41	3. 90	—. 90
80	4. 30	. 33	3. 42	. 00	2. 86	—1. 00	5. 31	. 00	5. 00	. 35	2. 71	—. 65
90	2. 37	. 18	1. 96	. 06	1. 86	— . 57	3. 21	. 11	2. 76	. 21	1. 38	—. 35
95	1. 30	. 10	1. 12	. 12	1. 34	— . 07	2. 00	. 15	1. 52	. 12	. 75	—. 19
100	. 13	. 00	. 29	. 21	. 45	. 45	. 61	. 61	. 27	. 00	. 00	. 00
Rad. L. E.	------	------	------	------	------	------	------	------	------	------	. 957	. 625



Airfoils 506 to 523 tested at approximately 20 atmospheres

Chart No. 13

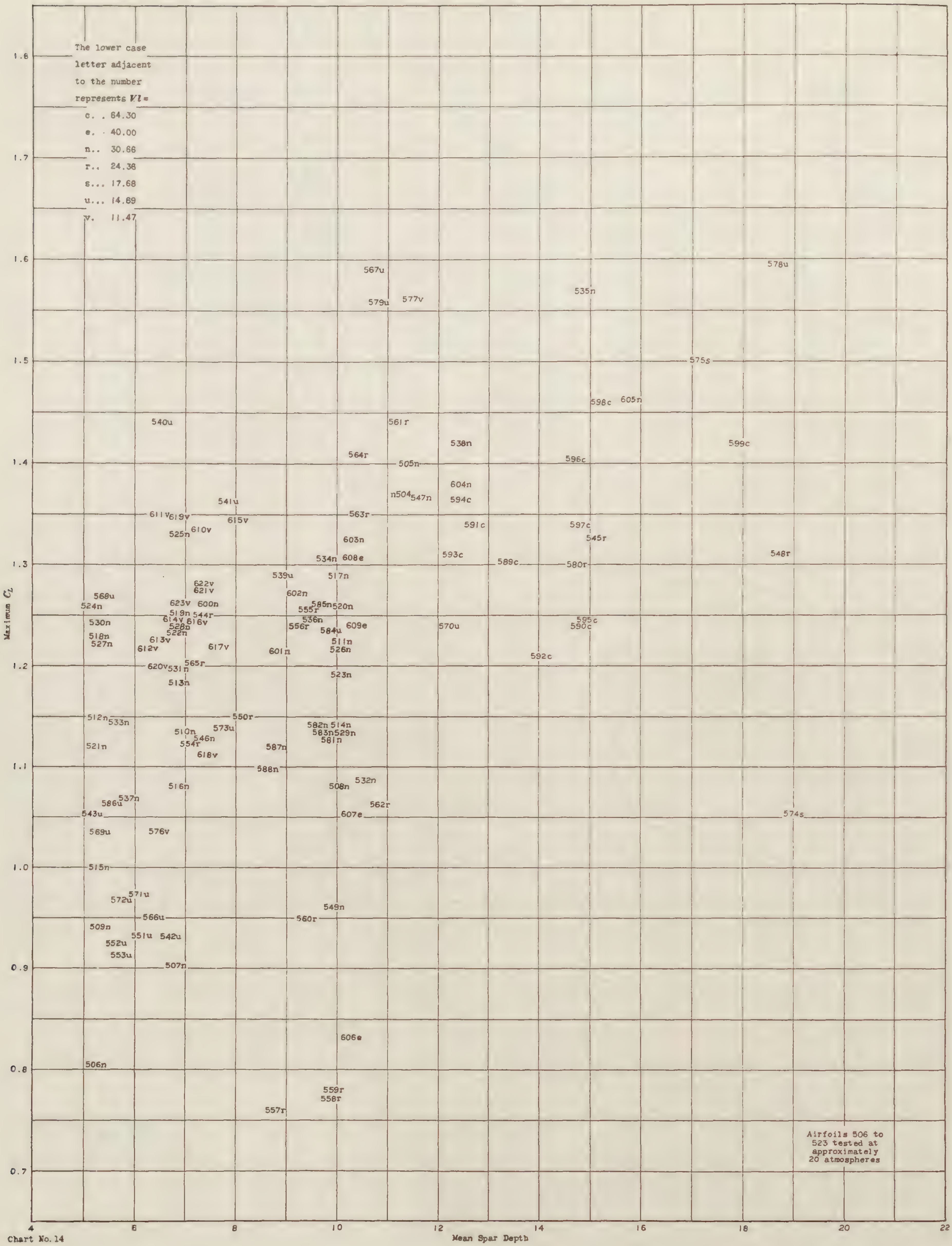

The lower case
letter adjacent
to the number
represents Vl =
c. . 64.30
e. . 40.00
n. . 30.86
r. . 24.38
s. . . 17.68
u. . . 14.89
v. 11.47
578u
567u
535n
579u
577v
575s
598c
605n
540u
561r
599c
538n
564r
596c
505n
604n
n504
547n
594c
541u
611v
619v
615v
563r
591c
597c
525n
610v
545r
603n
534n
608e
593c
589c
580r
548r
539u
517n
622v
621v
602n
568u
623v
600n
585n
520n
524n
519n
544r
555r
614v
616v
536n
530n
528n
556r
609e
570u
595c
590c
522n
584u
518n
613v
511n
527n
612v
617v
526n
601n
592c
620v
531n
565r
523n
513n
512n
533n
550r
582n
514n
573u
583n
529n
510n
581n
546n
554r
587n
521n
618v
588n
532n
516n
508n
537n
586u
562r
543u
607e
574s
569u
576v
515n
571u
572u
549n
566u
560r
509n
551u
542u
552u
553u
507n
606e
506n
559r
558r
557r
Airfoils 506 to
523 tested at
approximately
20 atmospheres
Maximum C_L
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
4
6
8
10
12
14
16
18
20
22
Mean Spar Depth

Chart No. 14

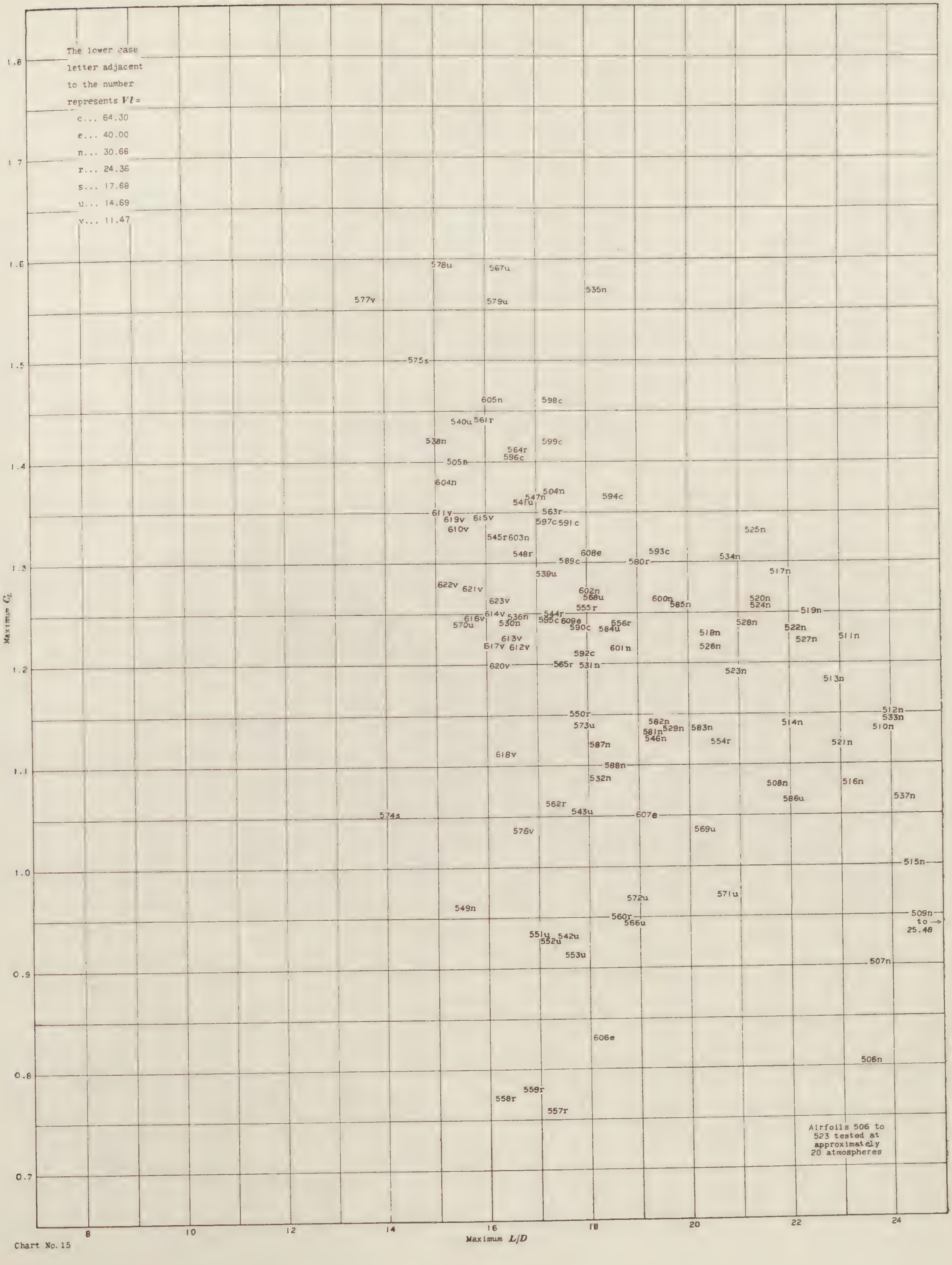

The lower case letter adjacent to the number represents Vl =
c... 64.30
e... 40.00
n... 30.66
r... 24.36
s... 17.68
u... 14.69
v... 11.47
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
Maximum C_L
8
10
12
14
16
18
20
22
24
Maximum L/D
578u
567u
535n
577v
579u
575s
605n
598c
540u
561r
538n
599c
564r
596c
505n
604n
504n
547n
541u
594c
611v
563r
619v
615v
597c
591c
610v
525n
545r
603n
548r
608e
593c
589c
580r
534n
539u
517n
622v
621v
602n
568u
623v
600n
585n
520n
524n
555r
519n
614v
536n
544r
616v
595c
609e
556r
570u
530n
590c
584u
528n
522n
518n
511n
613v
527n
617v
612v
601n
526n
592c
620v
565r
531n
523n
513n
512n
550r
533n
582n
510n
573u
529n
583n
514n
581n
546n
554r
587n
521n
618v
588n
532n
508n
516n
586u
537n
562r
574s
543u
607e
576v
569u
515n
572u
571u
549n
509n to → 25.48
560r
566u
551u
542u
552u
553u
507n
606e
506n
559r
558r
557r
Airfoils 506 to 523 tested at approximately 20 atmospheres

Chart No. 15

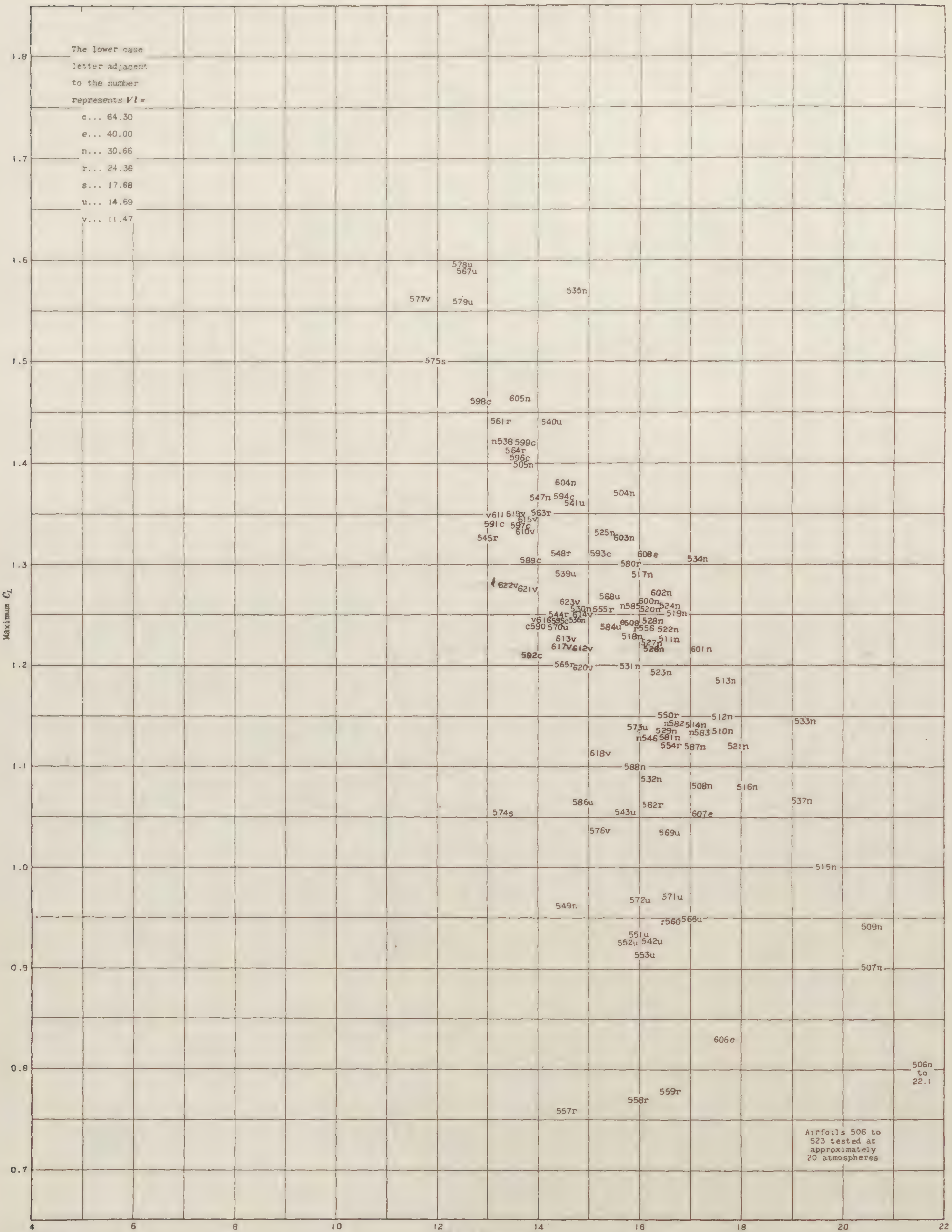

The lower case letter adjacent to the number represents Vl =
c... 64.30
e... 40.00
n... 30.66
r... 24.36
s... 17.68
u... 14.69
v... 11.47
Maximum C_L
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
4
6
8
10
12
14
16
18
20
22
L/D at 2/3 Maximum C_L
578u
567u
577v
579u
535n
575s
598c
605n
561r
540u
n538
599c
564r
596c
505n
604n
547n
594c
541u
504n
v611
619v
563r
615v
591c
597c
610v
545r
525n
603n
548r
593c
608e
534n
589c
580r
539u
517n
622v
621v
602n
568u
623v
600n
530n
555r
n585
524n
520n
519n
544r
614v
v616
595c
536n
528n
c590
570u
584u
e609
r556
522n
613v
518n
511n
527n
526n
601n
617v
612v
592c
565r
620v
531n
523n
513n
550r
512n
n582
514n
533n
573u
529n
n583
510n
n546
581n
554r
587n
521n
618v
588n
532n
508n
516n
586u
562r
537n
574s
543u
607e
576v
569u
515n
571u
572u
549n
r560
566u
509n
551u
552u
542u
553u
507n
606e
506n to 22.1
559r
558r
557r
Airfoils 506 to 523 tested at approximately 20 atmospheres

Chart No. 16

REPORT No. 245

METEOROLOGICAL CONDITIONS ALONG AIRWAYS

By W. R. GREGG
Weather Bureau

REPORT No. 245

METEOROLOGICAL CONDITIONS ALONG AIRWAYS

By W. R. Gregg

SUMMARY

This report was prepared at the suggestion of, and for publication by, the National Advisory Committee for Aeronautics and is an attempt to show the kind of meteorological information that is needed, and is in part available, for the purpose of determining operating conditions along airways. In general, the same factors affect these operating conditions along *all* airways though in varying degree, depending upon their topographic, geographic, and other characteristics; but in order to bring out as clearly as possible the nature of the data available, a specific example is taken, that of the Chicago-Dallas Airway on which *regular flying begins this year* (1926).

INTRODUCTION

The service that meteorology can render aeronautics may be considered broadly under two general headings: (1) Furnishing in convenient form statistical information based upon many years' records of the principal meteorological elements in different parts of the country; and (2) making quickly available current data and forecasts for specified airways, based upon detailed observations at points along those airways and at other places in contiguous areas. The latter type of service is required for the efficient operation of airways after they are organized and are working on a regular schedule basis. Statistical information, on the other hand, is needed also during the earlier organization stages of airways, when decision must be made regarding the location of landing fields, orientation of airdromes, adoption of flight schedules, etc. At the present time aeronautics in large measure is in the organization stage; and it seems opportune, therefore, to present for selected airways the sort of information that is needed, so far as it is available.

The information required in connection with the development of what may be called the ground organization—i. e., location and orientation of landing fields, airdromes, etc.—can best be obtained by a study of the local records at the places selected. There is often, for example, within small areas wide variation in wind gustiness owing to topographic irregularities, in the occurrence of fog because of differences in elevation, and in visibility since this varies materially on different sides of cities. Other factors to be considered are the average wind velocity, the frequency of various wind directions and velocities, and the occurrence of excessive precipitation, including heavy snow fall. A knowledge of these is necessary in deciding upon the best orientation of airdromes and runways and in providing adequate drainage for landing fields.

The adoption of flight schedules that can be satisfactorily maintained is dependent in part upon two of the factors above listed, visibility and frequency of fog, and in larger part upon several others, of which the most important are the frequency of low clouds, frequency and intensity of thunderstorms and excessive precipitation, and the characteristics of winds at flying levels, particularly the frequency of head and cross winds of sufficient velocity to cut down appreciably the ground speed of the aircraft. Although the data required for this purpose are far from being as complete as they should be, there nevertheless is sufficient information for certain parts of the country to justify the preparation of a preliminary survey or summary which can be revised and improved as added material is accumulated.

THE CHICAGO-DALLAS AIRWAY

The Chicago-Dallas Airway passes through Chicago, Moline, St. Joseph, Kansas City, Wichita, Oklahoma City, Dallas, and Fort Worth. (See fig. 1.) Continuous records of weather conditions have been kept for many years at these places, with the single exception of Moline, and in this case there are available the records at Davenport, which is directly across the Mississippi River. The records at these places are confined to surface conditions, except that they include the kind, amount, and direction of clouds. Visibility has thus far not been observed regularly.

Upper air observations have, however, been made at four places not far from this airway, viz, Royal Center, Ind., Drexel, Nebr., Broken Arrow, Okla., and Groesbeck, Tex. Their locations are shown in Figure 1. At these stations regular observations have been made of wind direction and velocity at different levels, heights of clouds, particularly of the lower forms, and visibility. It is thus possible, by utilizing the data from both surface and upper air stations, to gain a very good idea concerning the conditions which on the average will be experienced in flights along the Chicago-Dallas Airway. The meteorological factors or elements of most importance in connection with flight schedules are visibility; frequency of fog and low clouds; frequency and intensity of precipitation; frequency and intensity of thunderstorms; and upper winds, particularly the frequency of winds of different directions and velocities.

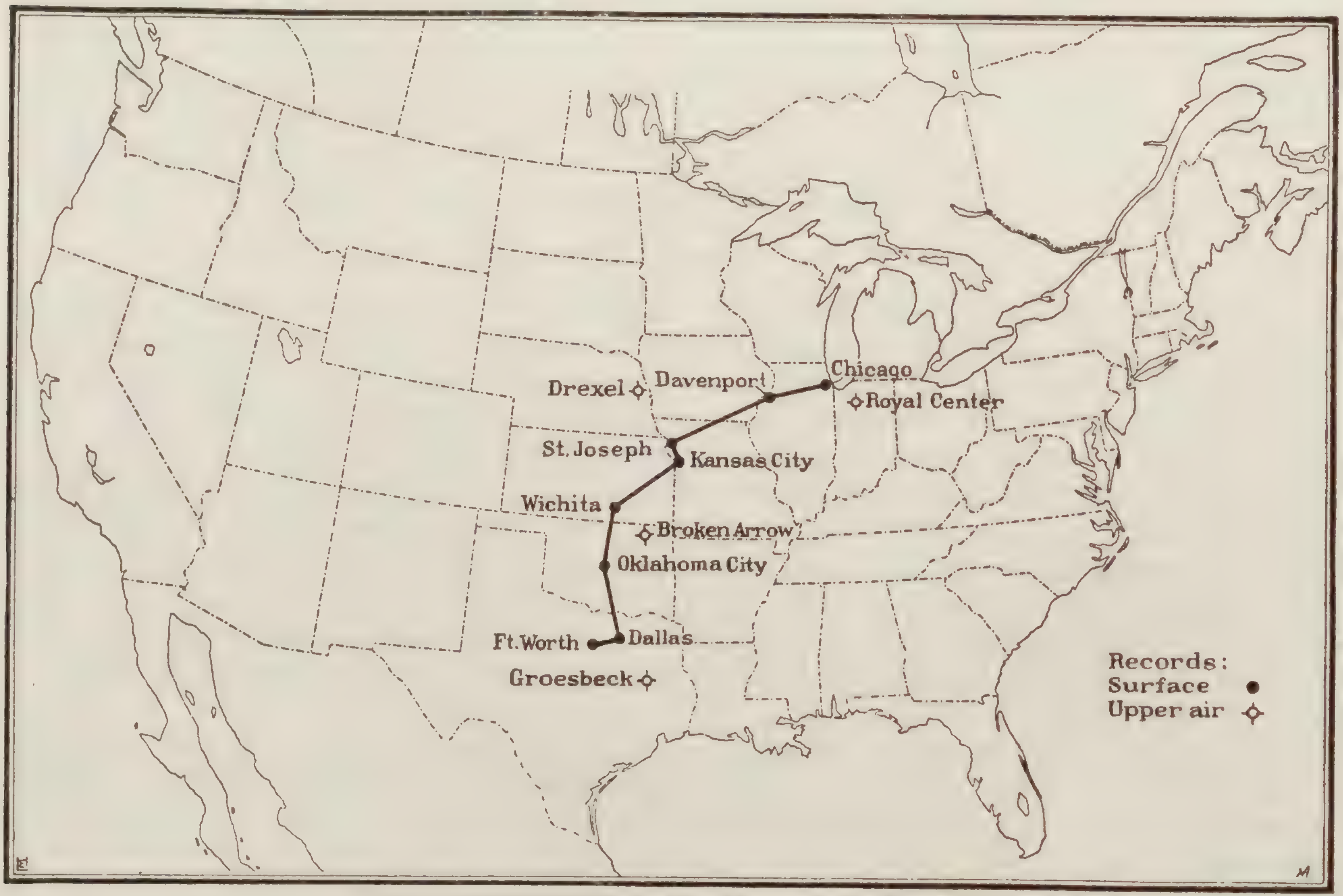


FIG. 1.—Meteorological stations along Chicago-Dallas Airway

VISIBILITY

For several years horizontal visibility has been observed twice daily at the four aerological stations above named, viz, Royal Center, Drexel, Broken Arrow, and Groesbeck. The observations are made by noting the greatest distance to which prominent objects on the earth's surface can be seen. An arbitrary scale of distances is used, as follows: 160, 650, 1,600, 3,300, 6,600, 13,100, 23,000, 39,400, and 98,400 feet.[1] Aeronautics is most concerned with the lower values, but in Table I frequencies for the season and year are given for 650, 1,600, 3,300, 13,100, and 23,000 feet, the stations being given in the order of their locations from north to south along the airway. These stations are at a considerable distance from large cities, and the data therefore refer to conditions in the country where naturally most of the flying will be done. Visibilities in and close to cities are on the average considerably less than those given in Table I, owing to smoke, dust, etc.

---

[1] The international visibility scale is 50, 200, 500, 1,000, 2,000, 4,000, 7,000, 12,000 and 30,000 meters, and observations in the United States are made in accordance with this scale. In the present paper English equivalents are used. This is true also of heights and wind velocities, although both units are employed in the tables. The conversion into English units, though not exact (i. e., to the nearest foot) is sufficiently close for all practical purposes.

It is evident that along this airway the frequency of very low visibilities is not a serious factor, those of less than 650 feet, for example, occurring only about 1 or 2 per cent of the time, with little seasonal, daily or regional variation. The higher visibilities, however, are most frequent in summer and least in winter, with spring and autumn agreeing closely with each other and with the annual mean. Moreover, the data show considerably better visibility in the afternoon than in the early morning and in the southern than in the northern sections of the airway.

TABLE I

AVERAGE SEASONAL AND ANNUAL FREQUENCY OF VISIBILITY LESS THAN 650, 1,600, 3,300, 13,100 AND 23,000 FEET AT CERTAIN STATIONS

ROYAL CENTER, IND., 7 A. M

Visibility less than		Spring	Summer	Autumn	Winter	Annual
Meters	*Feet*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
200	650	2	1	2	4	2
500	1,600	7	3	9	9	7
1,000	3,300	11	5	13	17	12
4,000	13,100	42	31	48	59	45
7,000	23,000	79	71	80	90	80

ROYAL CENTER, IND., 2 P. M.

200	650	1	0	1	2	1
500	1,600	4	1	5	7	4
1,000	3,300	6	2	6	11	6
4,000	13,100	20	8	16	33	19
7,000	23,000	46	30	44	63	46

DREXEL, NEBR., 7 A. M.

200	650	4	[1] 0	2	6	3
500	1,600	8	6	6	9	7
1,000	3,300	13	10	10	14	12
4,000	13,100	23	16	18	22	20
7,000	23,000	44	39	42	44	42

DREXEL, NEBR., 3 P. M.

200	650	1	0	1	4	1
500	1,600	5	3	5	7	5
1,000	3,300	6	4	6	10	7
4,000	13,100	15	7	12	18	13
7,000	23,000	38	29	36	42	36

BROKEN ARROW, OKLA., 7 A. M.

200	650	1	[1] 0	2	2	1
500	1,600	6	3	6	8	6
1,000	3,300	10	5	11	16	11
4,000	13,100	25	14	26	31	24
7,000	23,000	53	43	59	65	55

BROKEN ARROW, OKLA., 3 P. M.

200	650	[1] 0	0	[1] 0	1	[1] 0
500	1,600	4	1	4	7	4
1,000	3,300	5	1	5	10	5
4,000	13,100	12	2	12	18	11
7,000	23,000	34	15	28	43	30

[1] Less than 0.5 per cent.

TABLE I—Continued

AVERAGE SEASONAL AND ANNUAL FREQUENCY OF VISIBILITY LESS THAN 650, 1,600, 3,300, 13,100 AND 23,000 FEET AT CERTAIN STATIONS—Continued

GROESBECK, TEX., 7 A. M.

Visibility less than—		Spring	Summer	Autumn	Winter	Annual
Meters	*Feet*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
200	650	1	0	1	3	1
500	1,600	4	1	4	8	4
1,000	3,300	13	6	12	20	13
4,000	13,100	16	8	15	24	16
7,000	23,000	30	18	30	39	29

GROESBECK, TEX., 2 P. M.

200	650	[1] 0	0	0	1	[1] 0
500	1,600	2	1	3	6	3
1,000	3,300	3	1	3	9	4
4,000	13,100	4	1	5	11	5
7,000	23,000	12	7	10	19	12

[1] Less than 0.5 per cent.

These characteristic differences for visibilities less than 1,600 and 13,100 feet, are shown in greater detail in Figures 2 and 3.

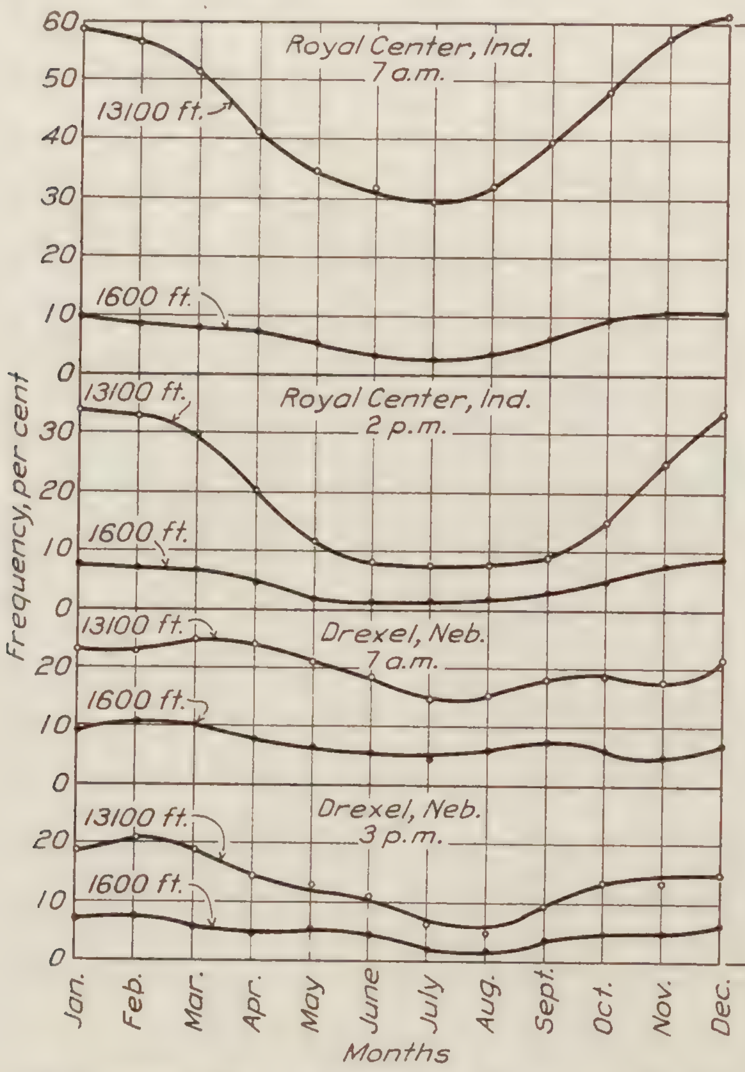


FIG. 2.—Annual variation in frequency of visibilities less than 1,600 and 13,100 feet at Royal Center, Ind., and Drexel, Nebr.

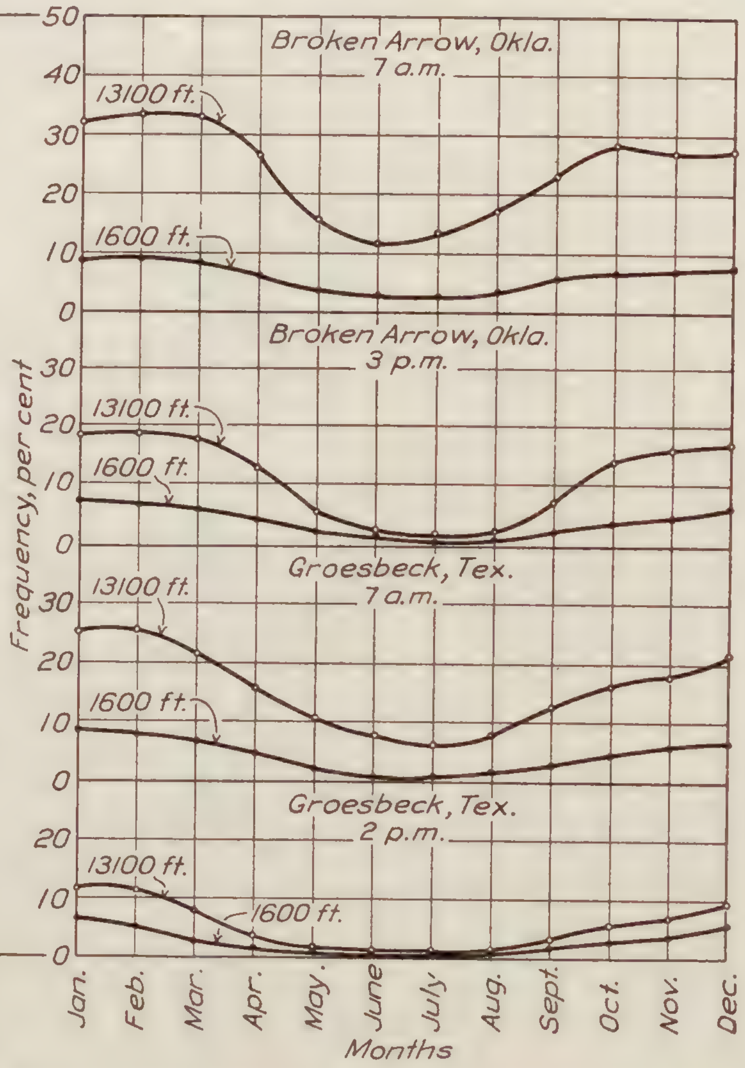


FIG. 3.—Annual variation in frequency of visibilities less than 1,600 and 13,100 feet at Broken Arrow, Okla., and Groesbeck, Tex.

It should be borne in mind that the data here presented are for *horizontal* visibilities only. In some cases, owing to low clouds, the vertical visibility may be very low, while that in a horizontal sense is relatively high. As a rule, however, the latter is low also when this condition prevails. Horizontal visibility is observed in two or more directions, north and south for example, and an average value taken. Observations are made on all days, including those in which rain or snow is falling.

FOG AND LOW CLOUDS

Dense fog is of such infrequent occurrence in the interior portions of the country that it offers no real obstacle to the maintenance of flight schedules. In general there are less than 10 days with dense fog per year. For the most part these fogs are of the radiation type, lasting therefore only during the night or until shortly after sunrise and being in general less than 300 feet deep. They are rarely widespread but occur in river bottoms or other low-lying places. At Chicago fogs are occasionally blown in from the lake or are caused by moist lake winds blowing over the colder surface of the ground. Occasionally also a combination of low clouds, smoke, and high humidity produces a condition closely resembling fog, the so-called "dark days." Such conditions fortunately are confined to the city limits and moreover do not as a rule occur more than four or five times a year, usually in the period December to March.

TABLE II

AVERAGE SEASONAL AND ANNUAL FREQUENCY OF CLOUDS BELOW SELECTED HEIGHTS AT CERTAIN STATIONS

ROYAL CENTER, IND., 7 A. M.

Height		Spring	Summer	Autumn	Winter	Annual
Meters	*Feet*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
150	500	5	2	6	11	6
300	1,000	11	5	12	18	11
500	1,600	18	8	17	27	17
1,000	3,300	26	12	27	40	26
1,500	4,900	31	16	31	46	31

ROYAL CENTER, IND., 2 P. M.

150	500	2	[1] 0	2	5	2
300	1,000	5	1	5	11	6
500	1,600	13	2	11	23	12
1,000	3,300	26	8	20	41	24
1,500	4,900	34	18	28	46	32

DREXEL, NEBR., 7 A. M.

150	500	6	5	5	7	6
300	1,000	11	8	8	11	10
500	1,600	17	11	12	17	14
1,000	3,300	22	15	18	23	20
1,500	4,900	25	18	20	27	23

DREXEL, NEBR., 3 P. M.

150	500	1	1	2	3	2
300	1,000	3	2	5	7	4
500	1,600	8	4	8	14	8
1,000	3,300	18	10	21	24	18
1,500	4,900	25	17	21	27	22

BROKEN ARROW, OKLA., 7 A. M.

150	500	6	3	8	11	7
300	1,000	9	4	11	16	10
500	1,600	13	6	15	21	14
1,000	3,300	22	9	19	27	19
1,500	4,900	24	11	21	30	22

BROKEN ARROW, OKLA. 3 P. M.

150	500	2	1	2	5	2
300	1,000	4	1	5	9	5
500	1,600	8	2	9	15	9
1,000	3,300	16	4	14	25	15
1,500	4,900	22	9	17	26	19

GROESBECK, TEX., 7 A. M.

150	500	10	7	11	17	11
300	1,000	13	9	14	21	14
500	1,600	23	14	18	28	21
1,000	3,300	32	16	23	38	27
1,500	4,900	35	17	26	41	30

[1] Less than 0.5 per cent.

TABLE II—Continued

AVERAGE SEASONAL AND ANNUAL FREQUENCY OF CLOUDS BELOW SELECTED HEIGHTS AT CERTAIN STATIONS—Continued

GROESBECK, TEX., 2 P. M.

Height		Spring	Summer	Autumn	Winter	Annual
Meters	*Feet*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
150	500	2	[1] 0	2	5	2
300	1,000	3	1	3	8	4
500	1,600	6	2	7	14	7
1,000	3,300	14	5	13	24	14
1,500	4,900	20	8	18	32	19

[1] Less than 0.5 per cent.

The frequencies, seasonal and annual, of clouds of different heights are given in Table II. The heights of most interest in aviation are the three lower ones, 500, 1,000, and 1,600 feet, and the frequencies for two of these, 500 and 1,600, are shown also in Figures 4 and 5. A fairly pronounced diurnal variation is apparent in all seasons, low clouds being about twice as frequent in early morning as in the afternoon, with an even greater difference than this for the lowest clouds, 500 feet or less. Summer shows the lowest frequency and winter the highest, with the other two seasons approximately equal and differing little from the annual mean. So far as the airway as a whole is concerned, it appears that the central portion has a slightly smaller frequency of low clouds than have the northern and southern sections, the difference being least in summer.

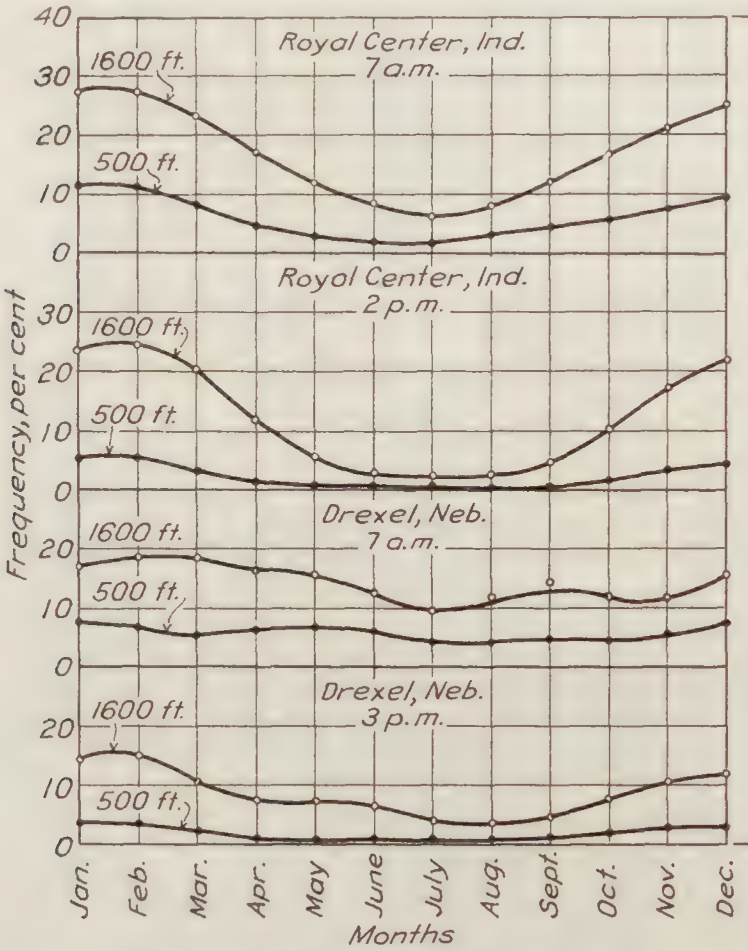


FIG. 4.—Annual variation in frequency of clouds below 500 and 1,600 feet, at Royal Center, Ind., and Drexel, Nebr.

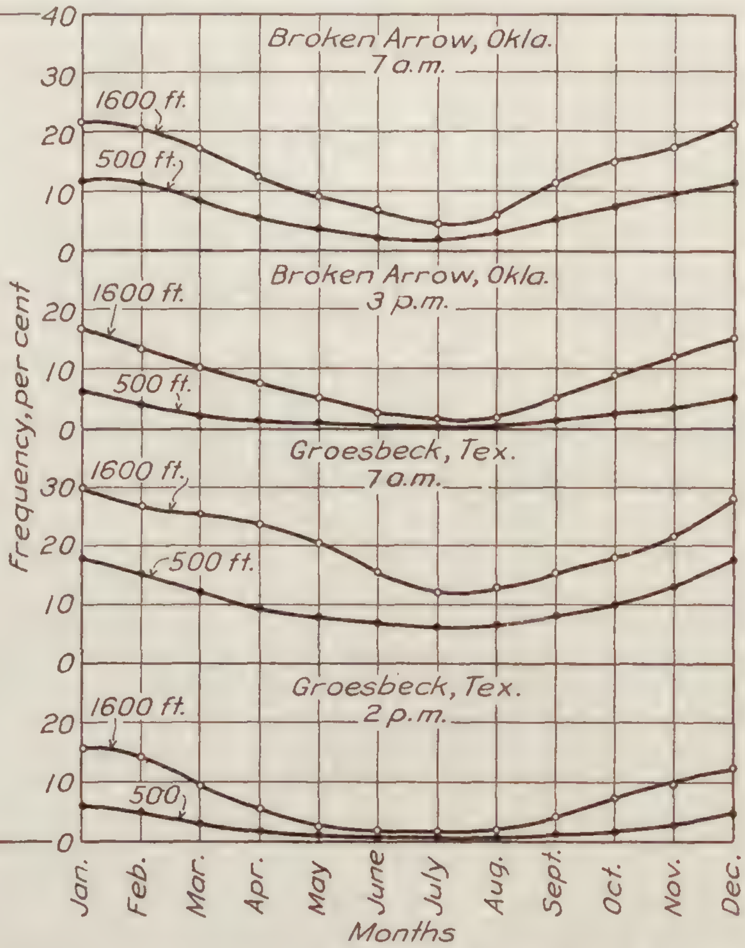


FIG. 5.—Annual variation in frequency of clouds below 500 and 1,600 feet at Broken Arrow, Okla., and Groesbeck, Tex.

The close relationship between visibility and the occurrence of low clouds is apparent from a comparison of Table I and Figures 2 and 3 with Table II and Figures 4 and 5. To a certain extent the frequency of low clouds, as presented in Table II, may be accepted also as an index of vertical as well as horizontal visibility.

PRECIPITATION

The average annual precipitation along the entire airway, Chicago to Fort Worth, is approximately 35 inches. Of this, some 60 to 70 per cent occurs during the six months, April to September, inclusive. During this period, moreover, there is more rain at night than in the daytime, the heaviest being near sunrise and the least in the early afternoon. For the region as a whole about 55 to 60 per cent occurs between 7 p. m. and 7 a. m., the amount being somewhat less than this in northern Illinois and northeastern Texas and slightly greater along the remainder of the airway.

The number of days with precipitation in measurable amounts, 0.01 inch or more, decreases from about 120 at Chicago to somewhat less than 80 at Dallas and Fort Worth. The seasonal distribution varies somewhat in different sections of the airway. For example, at Chicago the average number per month is about 9 from July to November, inclusive, and 11 during the remainder of the year; at St. Joseph, Mo., 6 in autumn and winter and 10 in spring and summer; and at Oklahoma City, 8 to 10 in spring and 6 in the other months.

Fortunately the days with light to moderate falls, 0.01 to 0.25 inch, form a fairly large percentage of the total number, about 65 per cent at Chicago and 60 at Fort Worth. Of the remainder nearly all have amounts from 0.26 to 1 inch. Falls in excess of 2 inches occur on the average only once or twice a year.

Snowfall varies widely in different sections of this airway. The average annual amount is about 30 to 35 inches at Chicago, 30 at Davenport, 20 at St. Joseph and Kansas City, 5 at Oklahoma City, and 1 to 5 at Dallas and Fort Worth. The snow problem is thus a serious one only in the northern third of the airway, and even here it is less serious than farther east. Really heavy falls are not frequent, 10 to 11 inches in 24 hours being about the limit, with 13 as the record for Chicago. Only rarely, moreover, is the accumulated amount on the ground more than this. January and February are the worst months.

Snow in measurable amounts, 0.1 inch or more, occurs on about 35 days at Chicago, decreasing to 3 or 4 at Dallas and Fort Worth. The number of days with snow cover varies from nearly 60 at Chicago and Davenport to 1 or 2 at Dallas and Fort Worth.

THUNDERSTORMS

The average frequency of thunderstorms at selected places along the airway is given in Table III. May to August are the months of greatest frequency, thunderstorms occurring then on about one day in four. During the four months, November to February inclusive, the number of thunderstorms is so small that they do not constitute a serious factor so far as flight schedules are concerned.

The characteristics of thunderstorms are too well known to need discussion here. In one respect, however, those of the central part of the United States are unique. In practically all other parts of the world they are most frequent when convection is most active, viz, during the afternoon, and least frequent during the night and early morning. In the Central States, on the other hand, particularly in Iowa, Nebraska, Kansas, and northwestern Missouri, more thunderstorms occur at night than in the daytime, the ratio being as high as 2 to 1 in summer at Lincoln, Nebr. Even at Chicago, the number from 6 p. m. to 6 a. m. is almost exactly the same as that during the remaining 12 hours. Night thunderstorms are frequently of considerable severity and accompanied by heavy rainfall. In fact the nocturnal maximum of precipitation in summer, already discussed, is directly related to this distribution of thunderstorm frequency.

TABLE III

AVERAGE NUMBER OF DAYS WITH THUNDERSTORMS ALONG THE CHICAGO-FORT WORTH AIRWAY

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Chicago	(1)	(1)	3	3	5	8	7	7	5	2	1	(1)	41
Davenport	(1)	(1)	2	3	7	8	8	7	6	2	1	(1)	44
St. Joseph	(1)	(1)	3	4	7	9	8	8	7	2	1	(1)	49
Kansas City	1	1	4	5	8	10	10	9	7	3	1	(1)	59
Oklahoma City	1	1	3	5	7	9	6	7	5	3	1	(1)	48
Dallas	2	3	4	8	8	8	5	7	4	3	2	2	56
Fort Worth	2	2	4	7	9	8	6	7	5	3	1	1	55

[1] Considerably less than 1 on the average.

TEMPERATURE

Air temperatures have less influence upon the maintenance of schedules and upon operations generally along airways than have the other meteorological factors discussed in this paper. However, a knowledge of them is of sufficient interest perhaps in connection with the comfort of pilots and passengers to justify a brief statement.

At the surface the average temperature for the year is about 50° F. at Chicago, increasing quite regularly southward to about 65° at Dallas and Fort Worth. In all parts of this airway the coldest month as a rule is January, with a mean of 20° to 25° at Chicago and 45° at Dallas and Fort Worth; and the warmest is July, with 70° to 75° and 80° to 85°, respectively. Extremes of temperature are not uncommon, values above 100° having been observed over this entire region, though most frequently, of course, in the southern portion. Here, however, the hot spells are usually very dry. Temperatures below zero are occasionally observed, the lowest ever recorded being about −30° in northern Illinois and −10° in northeastern Texas. The average number of days in a year with freezing or below ranges from slightly more than 100 in the northern part to about 35 in the southern.

For the year as a whole the temperature decreases with altitude at the rate of about 3° F. per 1,000 feet. There is, however, a rather large variation in this rate with season and with types of weather. When hot weather prevails at the surface, the temperature decrease is as a rule about double its normal value, the result being cool, comfortable conditions at a comparatively low altitude. On the other hand, with excessively low temperatures at the surface there is ordinarily found little change, frequently an increase, with altitude. For example, the lowest temperature ever observed up to 15,000 feet along this airway is −30° F., which is also approximately the surface record. In other words, during cold spells any provision that is made to insure comfort at the surface will also be sufficient for this purpose at flying levels up to 10,000 or 15,000 feet.

WINDS

Observations of upper air winds by means of kites and pilot balloons have been made twice daily at several places not far distant from the Chicago-Dallas Airway. A summary of the data indicates the desirability of considering wind conditions along three sections of the airway separately, viz, Chicago to Davenport, Davenport to St. Joseph, and St. Joseph to Fort Worth. The average velocities at certain heights along these sections are given in Table IV. These values are the means of all observations, irrespective of direction. It will be noted that at altitudes within which most flying is done, viz, 1,600 to 6,600 feet, there is little variation in different parts of the airway, velocities being slightly lower in the southern section than in the other two, a difference that increases somewhat at still greater altitudes.

TABLE IV

AVERAGE WIND VELOCITIES AT SELECTED LEVELS ALONG THE CHICAGO-DALLAS AIRWAY

Station	Surface		250 800		500 1,600		1,000 3,300		2,000 6,600		4,000 meters 13,100 feet	
	M.p.s.	*Ft./sec.*	*M.*	*Ft.*	*M.*	*Ft.*	*M.*	*Ft.*	*M.*	*Ft.*	*M.*	*Ft.*
Chicago to Davenport:												
Spring	4.8	15.7	8.7	28.5	9.9	32.5	10.2	33.5	12.4	40.7	16.7	54.8
Summer	3.5	11.5	6.2	20.3	6.8	22.3	7.0	23.0	8.0	26.2	10.0	32.8
Autumn	3.9	12.8	7.6	24.9	8.6	28.2	9.1	29.9	11.2	36.7	14.8	48.6
Winter	4.6	15.1	8.8	28.9	10.4	34.1	12.1	39.7	15.2	49.9	21.5	70.5
Annual	4.2	13.8	7.9	25.7	9.0	29.3	9.7	31.5	11.8	38.4	15.8	51.7
Davenport to St. Joseph:												
Spring	6.5	21.3	9.9	32.5	10.7	35.1	10.8	35.4	11.4	37.4	15.8	51.8
Summer	5.2	17.1	8.7	28.5	9.3	30.5	9.2	30.2	9.8	32.2	12.8	42.0
Autumn	5.8	19.0	9.8	32.2	10.8	35.4	11.1	36.4	12.2	40.0	17.6	57.7
Winter	6.2	20.3	10.0	32.8	11.7	38.4	13.2	43.3	15.3	50.2	20.6	67.6
Annual	5.9	19.4	9.6	31.5	10.6	34.8	11.1	36.3	12.2	40.0	16.7	54.8
St. Joseph to Fort Worth:												
Spring	5.7	18.7	10.0	32.8	11.3	37.1	10.9	35.8	11.7	38.4	15.7	51.5
Summer	4.2	13.8	7.9	25.9	9.0	29.5	7.8	25.6	6.5	21.3	7.3	24.0
Autumn	4.9	16.1	9.5	31.2	10.9	35.8	10.3	33.8	10.2	33.5	12.3	40.4
Winter	5.5	18.0	9.3	30.5	10.8	35.4	11.9	39.0	13.5	44.3	18.8	61.7
Annual	5.1	16.7	9.2	30.1	10.5	34.5	10.2	33.5	10.5	34.4	13.5	44.3

The sharp increase immediately above the surface is a characteristic feature in all parts of the world and is due to the decreasing effect of turbulence with altitude. This is peculiarly a nocturnal and early morning phenomenon. During the day there is convectional turbulence which extends to 3,000 feet or more and which results in lower velocities at all levels above the surface. In other words, a rather pronounced diurnal variation is found from 300 to approximately 5,000 feet, opposite in phase to that at the surface and of much greater amplitude—about 10 to 13 feet per second at 1,600 feet. The diurnal range is important in regular flight schedules, since it means that on the average in a region where the wind is prevailingly south, for example, flights northward can be made to best advantage at night or in the early morning, and those southward in the mid-afternoon. This is true for the St. Joseph to Fort Worth section of the airway, where southerly winds prevail at flying levels, as will be shown later.

A feature brought out by the values in Table IV is the relatively small increase from 1,600 to 3,300 feet. Although this is nearly always shown in the average of a large number of cases, it is not so decidedly characteristic as is the large increase from the surface to about 1,600 feet. In fact, the wind conditions between 1,600 and 3,300 feet vary markedly from a large increase to a sharp decrease with height. The latter is the more frequent, particularly in the summer half of the year, when even the average shows a decrease. In the southern section of the airway wind velocities during summer show, on the average, little change at all levels up to 20,000 or 25,000 feet.

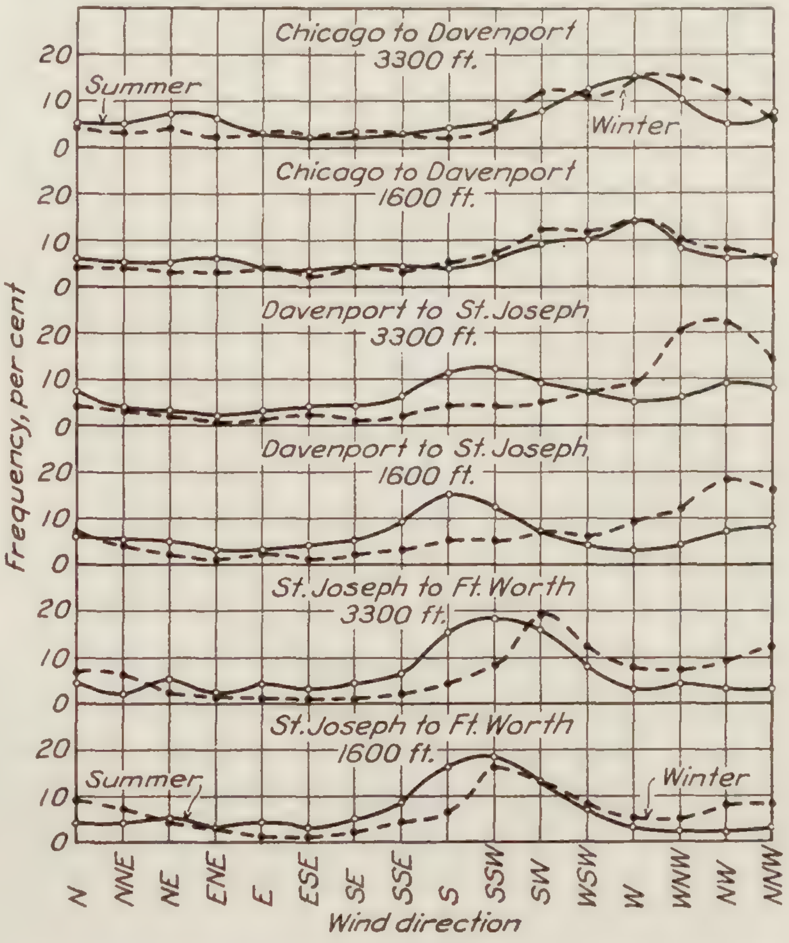


FIG. 6.—Frequency of different wind directions at 1,600 and 3,300 feet along certain sections of the Chicago-Dallas Airway

The average annual frequencies of different wind directions are given in Table V, and the summer and winter values for 1,600 and 3,300 feet only are shown in Figure 6. A marked south component is evident in the lower levels in all parts of the airway. It is most pronounced, however, between St. Joseph and Fort Worth and in the summer half of the year. A conspicuous feature brought out by Table V is the very decided preponderance of winds from west to northwest at the higher levels, particularly in the northern part of the airway.

TABLE V

AVERAGE ANNUAL FREQUENCY OF UPPER WINDS OF DIFFERENT DIRECTIONS ALONG THE CHICAGO-DALLAS AIRWAY

	Altitude					
	Surface	250 meters, 800 feet	500 meters, 1,600 feet	1,000 meters, 3.300 feet	2,000 meters, 6,600 feet	4,000 meters, 13,100 feet
Chicago to Davenport:	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
N	4	5	5	5	5	3
NNE	4	5	4	4	3	3
NE	5	4	4	5	3	1
ENE	5	4	4	3	1	1
E	4	4	4	3	2	1
ESE	4	3	3	2	1	1
SE	5	4	3	2	1	1
SSE	6	5	4	4	3	1

TABLE V—Continued

AVERAGE ANNUAL FREQUENCY OF UPPER WINDS OF DIFFERENT DIRECTIONS ALONG THE CHICAGO-DALLAS AIRWAY—Continued

	Altitude					
	Surface	250 meters, 800 feet	500 meters, 1,600 feet	1,000 meters, 3,300 feet	2,000 meters, 6,600 feet	4,000 meters, 13,100 feet
Chicago to Davenport—Continued.	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
S	8	7	6	4	3	4
SSW	9	9	9	7	5	3
SW	10	11	11	11	9	7
WSW	9	10	11	12	13	8
W	8	10	12	14	14	17
WNW	6	8	8	10	17	20
NW	5	5	6	8	12	21
NNW	4	6	6	6	8	8
Calm	4	[1] 0	[1] 0	0	[1] 0	[1] 0
Davenport to St. Joseph:						
N	7	7	7	6	4	4
NNE	6	5	4	3	2	2
NE	4	4	4	3	1	1
ENE	3	3	2	1	1	1
E	3	3	3	2	1	1
ESE	4	3	3	3	1	1
SE	6	5	4	3	2	1
SSE	8	7	6	4	2	1
S	10	10	10	8	3	1
SSW	8	10	10	9	7	2
SW	6	7	7	8	9	6
WSW	5	5	5	7	9	8
W	4	4	6	8	12	19
WNW	7	6	7	11	19	22
NW	9	11	11	14	18	21
NNW	9	10	11	10	9	9
Calm	1	[1] 0	[1] 0	0	[1] 0	[1] 0
St. Joseph to Fort Worth:						
N	8	7	6	6	4	5
NNE	7	7	6	4	3	3
NE	4	5	5	4	2	3
ENE	3	3	3	2	2	2
E	2	2	2	3	2	2
ESE	4	2	2	2	2	2
SE	7	4	4	3	2	2
SSE	13	9	6	4	4	2
S	15	17	14	10	6	3
SSW	11	16	18	16	10	5
SW	6	9	11	16	14	7
WSW	3	4	6	9	13	11
W	2	3	4	5	9	15
WNW	3	2	3	4	9	16
NW	4	5	4	5	10	13
NNW	6	5	6	7	8	9
Calm	2	[1] 0	[1] 0	[1] 0	[1] 0	0

[1] Less than 0.5 per cent.

Table 6 gives the frequency of different velocities for summer, winter, and the year. The annual values are means of those in all four seasons and represent quite closely the spring and autumn conditions; the latter are therefore not included in this table.

As would naturally be expected, a very marked seasonal variation is shown, particularly in the higher levels. At 6,600 feet, for example, velocities of 65 ft./sec. and above occur in winter from 10 to 15 per cent of the time, as against 1 to 4 in summer. At 1,600 and 3,300 feet, where most flying is done, strong winds occur somewhat more frequently in both seasons in the section between Davenport and St. Joseph than in the other parts of the airway. In summer, however, they are not a serious factor in any section.

The frequency of low wind velocities does not vary greatly with direction. High velocities, on the other hand, seldom occur with easterly directions, as is well shown in Figures 7 and 8, which give the annual frequencies, at 1,600 and 3,300 feet, respectively, of velocities of 22 and 33 M. P. H. and over along the three sections of the airway. These indicate that from St. Joseph to Fort Worth south component winds at moderate altitudes are not only more frequent but also have higher velocities than do north component winds. Thus, at 3,300 feet, S. to WSW. winds of 22 M. P. H. or more occur 26 per cent of the time or on about one day in four throughout the year. Curves for the seasons, not reproduced here, show decidedly higher frequencies in winter than in summer, especially with west component winds.

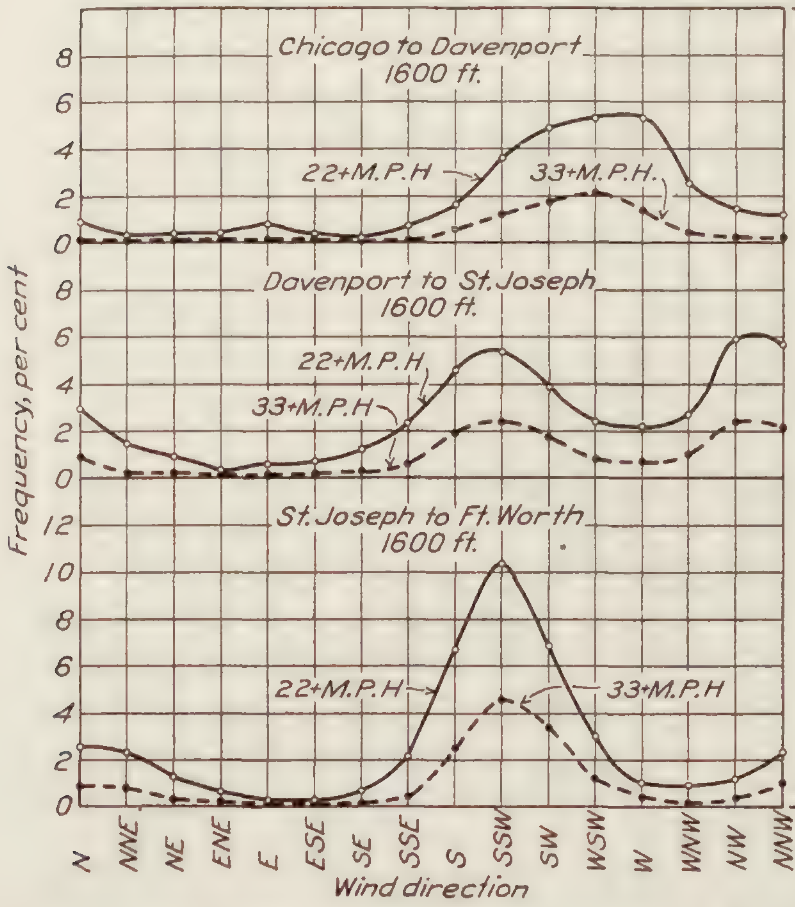


FIG. 7.—Average annual frequency of winds of 22 and 33 M. P. H. and over at 1,600 feet, classified by direction

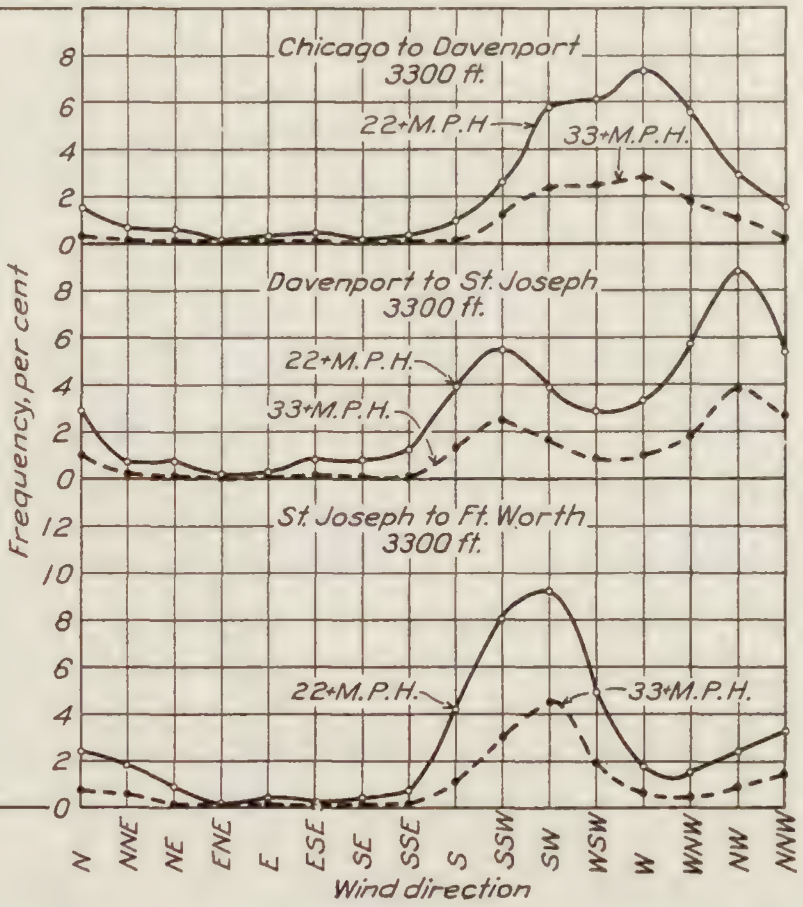


FIG. 8.—Average annual frequency of winds of 22 and 33 M. P. H. and over at 3,300 feet, classified by direction

TABLE VI

AVERAGE SUMMER, WINTER, AND ANNUAL FREQUENCY OF UPPER WINDS OF DIFFERENT VELOCITIES ALONG THE CHICAGO-DALLAS AIRWAY

CHICAGO TO DAVENPORT

Velocity		Altitude					
		Surface	250 meters, 800 feet	500 meters, 1,600 feet	1,000 meters, 3,300 feet	2,000 meters, 6,600 feet	4,000 meters, 13,100 feet
M. p. s.	*Ft./sec.*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
				Summer			
0–9	0–31	99	92	84	81	73	64
10–19	32–63	1	8	16	19	26	34
20–29	64–96	0	0	[1]0	0	1	2
30+	97+	0	0	0	0	0	0
				Winter			
0–9	0–31	95	75	61	43	31	25
10–19	32–63	5	25	26	50	55	50
20–29	64–96	0	[1]0	3	7	13	19
30+	97+	0	0	[1]0	[1]0	1	6
				Annual			
0–9	0–31	95	78	68	61	52	44
10–19	32–63	5	22	30	35	41	43
20–29	64–96	0	[1]0	2	4	7	11
30+	97+	0	0	[1]0	[1]0	[1]0	2

TABLE VI—Continued

AVERAGE SUMMER, WINTER, AND ANNUAL FREQUENCY OF UPPER WINDS OF DIFFERENT VELOCITIES ALONG THE CHICAGO-DALLAS AIRWAY—Continued

DAVENPORT TO ST. JOSEPH

Velocity		Altitude					
		Surface	250 meters, 800 feet	500 meters, 1,600 feet	1,000 meters, 3,300 feet	2,000 meters, 6,600 feet	4,000 meters, 13,100 feet
M. p. s.	*Ft./sec.*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
		Summer					
0- 9	0-31	89	72	65	66	67	51
10-19	32-63	11	28	33	31	29	43
20-29	64-96	0	[1]0	2	3	4	6
30+	97+	0	0	0	0	0	0
		Winter					
0- 9	0-31	84	63	49	38	27	15
10-19	32-63	16	36	45	52	58	57
20-29	64-96	0	1	6	9	14	22
30+	97+	0	[1]0	[1]0	1	1	6
		Annual					
0- 9	0-31	85	66	57	54	47	37
10-19	32-63	15	33	39	41	46	45
20-29	64-96	0	1	4	5	6	15
30+	97+	0	[1]0	[1]0	[1]0	1	3

ST. JOSEPH TO FORT WORTH

		Summer					
0-9	0-31	98	93	68	76	86	83
10-19	32-63	2	7	30	23	13	17
20-29	64-96	0	0	2	1	1	[1]0
30+	97+	0	0	0	[1]0	[1]0	0
		Winter					
0-9	0-31	88	69	57	44	35	24
10-19	32-63	12	30	37	50	54	47
20-29	64-96	0	1	6	6	11	25
30+	97+	0	0	0	0	[1]0	4
		Annual					
0-9	0-31	90	71	57	57	57	50
10-19	32-63	10	28	38	40	38	37
20-29	64-96	[1]0	1	5	3	5	12
30+	97+	0	0	[1]0	[1]0	[1]0	1

[1] Less than 0.5 per cent.

Resultant winds,[1] seasonal and annual, are given in Table VII. Features of chief interest are: The large seasonal variation in the upper levels; west component at all levels above the surface; and south component in the lower levels and north component in the upper, the height of change being greater in the southern than in the northern part of the airway.

Resultant winds have an important application in aeronautics. Earlier studies have shown that on the average, air-mail airplanes fly 21 ft./sec. faster from Chicago to New York than in the reverse direction. This value is almost exactly double the resultant wind, 11.2 ft./sec. along this route. In other words, the eastbound airplanes on the average have a tail wind of 11.2 ft./sec. and those westbound a head wind of the same strength. Thus, a knowledge of resultant winds makes possible a determination of flight schedules in each direction, providing the cruising speed of the aircraft is known. Assume this in the present case to be 147 ft./sec (100 M. P. H.), and assume also that flying is done at a height of 1,600 feet. The resultant speed of the aircraft can be found from the equation

$$S_r = S_a \cos \beta \pm S_w \cos a \qquad (1)$$

in which

S_r = resultant speed;

S_a = cruising speed of the aircraft;

S_w = resultant wind;

β = the angle between the heading of the aircraft and the course;

a = the angle between the resultant wind and the course.

---

[1] Resultant wind is the geometric or vector sum of the individual observations. It is most easily obtained by resolving the observations into their N and W (or S and E) components and adding these algebraically.

β, the angle that the aircraft must make with the course in order to stay on that course is computed from the equation

$$\sin \beta = \frac{S_w}{S_a} \sin \alpha \tag{2}$$

TABLE VII

RESULTANT WIND VELOCITIES ALONG THE CHICAGO-DALLAS AIRWAY

	Surface			Altitude											
				500 meters, 1,600 feet			1,000 meters, 3,300 feet			2,000 meters, 6,600 feet			4,000 meters, 13,100 feet		
	Dir.	Vel.		Dir.	Vel.		Dir.	Vel.		Dir.	Vel.		Dir.	Vel.	
		M./ *sec.*	*Ft./* *sec.*		*M./* *sec.*	*Ft./* *sec.*		*M./* *sec.*	*Ft./* *sec.*		*M./* *sec.*	*Ft./* *sec.*		*M./* *sec.*	*Ft./* *sec.*
Chicago to Davenport:															
Spring	S. 57 W.	1.2	3.9	S. 62 W.	3.3	10.8	S. 76 W.	3.8	12.5	N. 82 W.	5.5	18.0	N. 65 W.	8.5	27.9
Summer	S. 74 W.	.8	2.6	S. 88 W.	2.2	7.2	N. 85 W.	2.7	8.9	N. 73 W.	3.9	12.8	N. 62 W.	5.6	18.4
Autumn	S. 48 W.	1.5	4.9	S. 67 W.	3.4	11.2	S. 81 W.	4.6	15.1	W.	6.5	21.3	N. 82 W.	9.2	30.2
Winter	S. 55 W.	1.5	4.9	S. 73 W.	4.3	14.1	N. 87 W.	7.6	24.9	N. 78 W.	9.8	32.2	N. 72 W.	12.8	42.0
Annual	S. 56 W.	1.2	3.9	S. 71 W.	3.2	21.5	S. 87 W.	4.6	15.1	N 81 W.	6.4	21.0	N. 71 W.	8.9	29.2
Davenport to St. Joseph:															
Spring	S. 85 W.	.3	1.0	S. 63 W.	1.3	4.3	S. 85 W.	2.5	8.2	N. 86 W.	5.3	17.4	N. 73 W.	10.1	33.1
Summer	S. 5 E.	.9	3.0	S. 30 W.	2.1	6.9	S. 61 W.	2.7	8.9	N. 75 W.	4.3	14.1	N. 57 W.	6.9	22.6
Autumn	S. 80 W.	1.3	4.3	S. 76 W.	3.0	9.8	S. 87 W.	4.4	14.4	N. 80 W.	7.3	24.0	N. 73 W.	11.5	37.7
Winter	N.62 W.	2.5	8.2	N. 62 W.	5.9	19.4	N. 62 W.	7.4	24.3	N. 66 W.	11.1	36.4	N. 62 W.	13.5	44.3
Annual	N. 89 W.	.9	3.0	S. 88 W.	2.6	8.5	N. 84 W.	4.0	13.1	N. 75 W.	6.9	22.6	N. 66 W.	10.2	33.5
St. Joseph to Fort Worth:															
Spring	S.	1.8	5.9	S. 22 W.	3.9	12.8	S. 44 W.	4.4	14.4	S. 76 W.	5.8	19.0	N .77 W.	8.9	29.2
Summer	S. 13 E.	2.0	6.6	S. 21 W.	4.3	14.1	S. 29 W.	3.9	12.8	S. 45 W.	2.6	8.5	N. 49 W.	1.9	6.2
Autumn	S. 8 E.	1.2	3.9	S. 27 W.	3.4	11.2	S. 49 W.	3.5	11.5	S. 87 W.	4.0	13.1	N. 79 W.	6.5	21.3
Winter	S. 74 W.	1.0	3.3	S. 77 W.	3.1	10.2	S. 86 W.	5.2	17.1	N. 80 W.	8.0	26.2	N. 73 W.	12.0	39.4
Annual	S. 4 W.	1.3	4.3	S. 33 W.	3.6	11.8	S. 54 W.	3.9	12.8	S. 84 W.	4.8	15.7	N. 74 W.	7.2	23.6

The values of α for the three sections of the airway are, approximately,

Chicago to Davenport, 5°;
Davenport to St. Joseph, 47°;
St. Joseph to Fort Worth, 34°.

Substituting in (2), we find the following values of β:

Chicago to Davenport, 0°;
Davenport to St. Joseph, 2°;
St. Joseph to Fort Worth, 3°.

Then, from (1) we get, for S_r,

Chicago to Davenport, 100.0 ± 7.2 M. P. H.;
Davenport to St. Joseph, 99.9 ± 4.0 M. P. H.;
St. Joseph to Fort Worth, 99.9 ± 6.7 M. P. H.

These figures mean that on the average throughout the year, assuming cruising speed of 100 M. P. H. and flight at an altitude of 1,600 feet, the actual ground speed northward would be faster than that southward by the following amounts:

Chicago to Davenport, 21 ft./sec., or 14 M. P. H.
Davenport to St. Joseph, 12 ft./sec., or 8 M. P. H.
St. Joseph to Fort Worth, 19 ft./sec., or 13 M. P. H.

From equations (1) and (2) resultant speeds can be computed for other levels and also for the different seasons. It is evident, from Table VII, that at 13,100 feet neither direction would have much advantage over the other, since the resultant wind is more or less at right angles to the airway. It would therefore somewhat decrease the ground speed in both directions.

BIBLIOGRAPHY

Day, P. C. Summary of the Climatological Data for the United States, by Sections. Bulletin W.

Kincer, J. B. Atlas of American Agriculture: Section A of Part II—Precipitation and humidity.

Ward, R. DeC. The Climates of the United States. Ginn & Co. 1925.

Cox H. J.; Armington, J. H. The Weather and Climate of Chicago. University of Chicago Press. 1914.

Alexander, W. H. The distribution of thunderstorms in the United States. Monthly Weather Review, July, 1924.

Gregg, W. R. An Aerological Survey of the United States. Part 2, Observations by Means of Pilot Balloons. (To be published soon.)

Gregg, W. R.; Van Zandt, J. P. The wind factor in flight: An analysis of one year's record of the air mail. Monthly Weather Review, March, 1923.

Riley, J. A. The wind factor and the air mail southward from Kansas City. Monthly Weather Review, January, 1926.

REPORT No. 246

TABLES FOR CALIBRATING ALTIMETERS AND COMPUTING ALTITUDES BASED ON THE STANDARD ATMOSPHERE

By W. G. BROMBACHER
Bureau of Standards

REPORT No. 246

TABLES FOR CALIBRATING ALTIMETERS AND COMPUTING ALTITUDES BASED ON THE STANDARD ATMOSPHERE

By W. G. Brombacher

SUMMARY

This report was prepared by the Aeronautic Instruments Section of the Bureau of Standards under research authorization formulated and recommended by the subcommittee on aerodynamics and approved by the National Advisory Committee for Aeronautics.

During 1925 the assumption of an isothermal atmosphere which was in general use as the standard for the calibration of altimeters in the United States was replaced by a standard atmosphere which assumes an altitude-temperature relation closely corresponding to the average of upper air observations at latitude 40° in this country. The same standard atmosphere had already been adopted somewhat earlier in the United States as the aircraft performance standard.

National Advisory Committee for Aeronautics Technical Reports Nos. 147 and 218 give necessary constants, tables, and information. However, neither of these reports includes all of the tables required for the computation of actual altitudes nor those readily suitable for use in calibrating altimeters, since the altitude intervals for which data are given are not sufficiently small. The present report has been prepared specifically for these purposes.

The formulas which define the standard atmosphere are given in this report, together with other formulas giving the corrections to be applied to the standard altitude in order to obtain the actual altitude when the necessary observations of pressure and temperature are available.

The tables necessary for the use of this standard atmosphere in calibrating altimeters and in computing altitudes form the principal part of this report. In Table I are given the standard altitudes at pressure intervals of 0.1 millimeter of mercury in the range 87 to 200 millimeters of mercury and at intervals of 0.2 millimeter of mercury in the range 200 to 790 millimeters of mercury. In Table II standard altitudes are given at intervals of 0.01 inch of mercury in the range 3.4 to 31.09 inches of mercury. In Table III are given the pressure in inches and millimeters of mercury, the temperature, the mean temperature, and the corresponding isothermal altitude at every 500-foot interval of standard altitude in the range −1,000 to +50,000 feet. Temperature corrections for use in computing altitudes from observed pressures and temperatures are given in Table IV.

An example of the computation of actual altitude from the necessary observations of pressure and temperature is also included.

INTRODUCTION

In the isothermal atmosphere which had been used for calibrating altimeters in the United States previous to 1925 the air is assumed to be at a temperature of +10° C. at all altitudes. (Reference 1.) This atmosphere represents average atmospheric conditions quite accurately up to an altitude of approximately 12,000 feet, and hence, as long as aircraft did not exceed this altitude, the altimeter reading was an approximate measure of the actual altitude. The ceiling of aircraft now far exceeds 12,000 feet, and on account of the low temperatures corresponding to these altitudes the assumption of an isothermal atmosphere at +10° C. no longer even approximates the actual average conditions, so that altimeters calibrated to this atmosphere no longer closely approximate the actual conditions.

A new altimeter calibration standard approximating average atmospheric conditions up to at least 50,000 feet was proposed at a conference held in December, 1924, at which the following organizations were represented: Bureau of Aeronautics of the United States Navy, Air Service of the United States Army, National Advisory Committee for Aeronautics, Bureau of Standards, United States Weather Bureau, and the National Aeronautic Association. The standard atmosphere which was proposed by this conference for use as an altimeter calibration standard has since been adopted by the organizations represented at this conference.

THE NEW STANDARD ATMOSPHERE

The standard atmosphere adopted as the new altimeter calibration standard has also been adopted as the standard for aircraft performance in the United States. The standard atmosphere is defined by an altitude-temperature-pressure relation in which an arbitrary altitude-temperature relation is assumed. The altitude-temperature assumption of this standard, a slight modification of that proposed by Toussaint (Reference 2), is extremely simple and approximates the average observed variation of temperature with altitude at latitude 40° in the United States (Reference 3). The standard atmosphere is defined completely in National Advisory Committee for Aeronautics Technical Report No. 218, "Standard Atmosphere—Tables and Data," by W. S. Diehl. The important formulas in this last report are also given here for the sake of completeness, together with the expression for the temperature correction to be used in computing actual altitudes from pressure and temperature observations. Absolute temperatures are equal to centigrade temperatures plus 273.

Symbols relating to the standard atmosphere:

Z=Standard altitude.
Z_{55}=Altitude at the lower limit of the isothermal layer.
T=Absolute temperature of the air at altitude Z.
T_o=Standard sea level temperature in degrees absolute.
T_m=Mean temperature of the air column below altitude Z in degrees absolute.
T_{m55}=Mean temperature in degrees absolute for Z_{55}.
p=Pressure of the air at altitude Z.
p_o=Standard sea level pressure.

Symbols relating to actual observations:

H=Actual altitude.
T_{ma}=The mean temperature, computed from observations, in degrees absolute.
C=Altitude correction due to deviation of the actual from the standard mean temperature.
p=Pressure of the air at altitude H.
p_o=Standard sea level pressure.

Formulas relating to standard atmosphere:

(*a*) Up to the isothermal layer—

$$T=288-aZ \tag{1}$$

$$T_o=288^\circ \text{ absolute}$$

$$T_m=\frac{aZ}{\log_e \dfrac{T_o}{T_o-aZ}} \tag{2}$$

$$a=0.0065000 \text{ for } Z \text{ in meters,}$$

$$=0.0019812 \text{ for } Z \text{ in feet.}$$

(*b*) At the lower limit of the isothermal layer—

$$T=-55^\circ \text{ C.}=218^\circ \text{ absolute,} \tag{3}$$

$$Z_{55}=35{,}332 \text{ feet}=10{,}769 \text{ meters,}$$

$$T_{m55}=251.378^\circ \text{ absolute.}$$

Formulas relating to standard atmosphere—Continued.

(*c*) In the isothermal layer—

$$T = -55^\circ \text{ C.} = 218^\circ \text{ absolute.} \tag{4}$$

$$T_m = \frac{Z}{\frac{Z_{55}}{T_{m55}} + \frac{Z - Z_{55}}{218}} \tag{5}$$

(*d*) For all standard altitudes—

$$Z = K \frac{T_m}{T_o} \log_{10} \frac{p_o}{p} \tag{6}$$

(*e*) For computing actual altitudes—

$$H = Z + C \tag{7}$$

$$H = K \frac{T_{ma}}{T_o} \log \frac{p_o}{p} \tag{8}$$

$$C = K \frac{T_{ma} - T_m}{T_o} \log \frac{p_o}{p}$$

$$= 63{,}691.8 \frac{\mathrm{T}_{ma} - \mathrm{T}_m}{\mathrm{T}_o} \log \frac{p_o}{p} \text{ feet.} \tag{9}$$

$$= \frac{T_{ma} - T_m}{T_m} Z.$$

(*f*) For formulas (6) and (8)—

K([1]) = 19,413.3 for Z in meters.

= 63,691.8 for Z in feet.

p_o = 760 mm of Hg. = 29.921 in Hg.

p is in same unit of pressure as p_o.

Attention should be called to the fact that whether the mean temperature T_{ma} in formula (8) is an harmonic or an arithmetic mean depends entirely on the data from which T_{ma} is to be computed. If the air temperatures are available for different *actual altitudes* then the harmonic mean temperature must be computed (Reference 4). This case occurs only infrequently. *When the actual altitude is to be computed from the following data obtained in flight, the arithmetic mean is invariably used.* If the air temperatures corresponding to various pressures are observed, then the temperatures may be plotted against log p or log $\frac{p_o}{p}$ for determining the mean. If instead, the altitudes indicated by an altimeter calibrated to an isothermal calibration standard are available, then the temperatures may be plotted against these altitudes directly. An example of this method of computation is given under the heading "Computation of Altitude from Pressure and Temperature Observations." If altitudes indicated by an altimeter calibrated to the new calibration standard are given, these altitudes should be converted to isothermal altitudes by means of Table III and the temperatures plotted against these isothermal altitudes.

DESCRIPTION OF THE TABLES

The method of computing the tables was as follows: For even standard altitudes differing by 500 feet in the range −1,000 to +50,000 feet, the air temperatures, mean temperatures, and then the pressures were computed to six significant figures. The results were checked by the method of differences. The standard altitude was then computed to one digit beyond those given in the table for the pressure range of Table I for every millimeter of mercury. The mean temperatures corresponding to every millimeter of mercury were secured from graphs of the computations of the mean temperatures and pressures for the 500-foot intervals of altitude. The altitudes corresponding to the values of pressure in tenths millimeters of mercury were found by interpolation. The altitude-pressure table with the pressures in inches of mercury was obtained by conversion and interpolation. All tables were checked by the method of differences. The accuracy of computation of Tables I and II is within 1 foot at the lower altitudes and 2 feet at the higher altitudes.

---

[1] The values of K adopted for the altimeter calibration standard differ in the last place from the values given in N. A. C. A. Technical Report No. 218, but the differences are small enough to be ignored.

Table I.—Altitudes are given at pressure intervals of 0.1 millimeter of mercury in the range 87 to 200 millimeters of mercury and at intervals of 0.2 millimeter of mercury in the range 200 to 790 millimeters of mercury.

Table II.—Altitudes are given at pressure intervals of 0.01 inch of mercury in the range 3.4 to 31.09 inches of mercury.

Table III.—The pressures in inches of mercury and millimeters of mercury are given for every 500-foot interval for the range −1,000 to +50,000 feet. The temperature of the air at the altitude and the mean temperature of the air column below the altitude are also given for each altitude. Furthermore, the altitudes corresponding to the pressures are also given for an isothermal atmosphere at a temperature of +10° C. The values of the latter are rounded off to the nearest 10 feet. Since the values of the pressures are rounded off from computations extending to six significant figures, it will be found that the pressures in inches and in millimeters do not always exactly correspond.

Table IV.—The temperature corrections (to be added algebraically to a standard altitude Z to give actual altitude H when the actual mean temperature differs from that of the standard atmosphere) are given for a useful range of mean temperature for each 2,000-foot interval of standard altitude up to 50,000 feet.

COMPUTATION OF ALTITUDE FROM PRESSURE AND TEMPERATURE OBSERVATIONS

Standard altitude.—The atmospheric pressure is measured simultaneously by suitable means at the surface of the earth and at the level of the aircraft. The standard altitude above the ground level is obtained by subtracting the altitude corresponding to the pressure at the surface from that corresponding to the free air pressure at the aircraft level, as given in either Table I or II.

Temperature correction.—The actual mean temperature of the air column extending from the ground to the level of the aircraft will rarely be the same as the corresponding mean temperature for the standard atmosphere. In computing altitudes accurately it is necessary to determine the actual mean temperature and to apply a correction to the indicated or standard altitude depending on this temperature. (Reference 5.)

To obtain the actual mean temperature of the air column the temperature of the free air at successive levels should be plotted against corresponding values of $\log \frac{p_o}{p}$ (or $\log p$) If the observations of temperature correspond to values of p obtained from an aneroid barometer, it is convenient to plot values of $\log p$ as abscissas. The altitudes indicated by an altimeter calibrated to the old isothermal standard are proportional to $\log \frac{p_o}{p}$, and so if such altimeter readings form part of the observations they can be plotted directly. If altitudes indicated by an altimeter calibrated to the new standard given in this paper form part of the observations, these altitudes should be converted to isothermal altitudes by means of Table III of this report (or more easily by either Table I or Table II of this report and Bureau of Standards Aeronautic Instruments Circular No. 3) before being plotted. The curve thus obtained is subdivided into equal divisions of isothermal altitude (or $\log p$). The number of divisions is determined largely by the number of observations and the accuracy of the data. The arithmetic mean of the air temperatures at the middle of each altitude division gives the actual mean temperature. The correction in Table IV corresponding to the mean temperature thus found and to the standard altitude is the desired temperature correction. *The correction must be obtained by interpolation between the next higher and the next lower altitudes in Table IV.*

Actual altitude.—The actual altitude *H* is the sum of the standard altitude and the temperature correction, proper attention being given to the sign of the latter. See equation (7).

EXAMPLE OF THE COMPUTATION OF ACTUAL ALTITUDE

Data.—Pressure of air at surface: 29.54 inches of mercury.
Elevation of surface above sea level= 800 feet.
Pressure of air at level of aircraft: 12.22 inches of mercury.
Temperature observations (from the log of a flight).

Isothermal altitude	Free air temperature	Isothermal altitude	Free air temperature
Feet	*° C.*	*Feet*	*° C.*
0	+28	12, 000	5
1, 000	23	13, 000	2. 5
2, 000	20	14, 000	+2
3, 000	18	15, 000	−1
4, 000	15	16, 000	−1
5, 000	12	17, 000	−4
6, 000	11	18, 000	−6
7, 000	11	21, 000	−11
8, 000	11	22, 000	−13
9, 000	9	23, 000	−14
10, 000	8	24, 000	−17
11, 000	7	24, 200	−18

Computations.—The temperatures have been plotted against isothermal altitude in Figure 1. The graph has been divided into 2,000 foot intervals and the mean temperature of the intervals determined by inspection and listed below:

Isothermal altitude interval	Mean temperature of interval	Isothermal altitude interval	Mean temperature of interval
Thousand feet	*° C.*	*Thousand feet*	*° C.*
0–2	+23. 5	14–16	0. 0
2–4	17. 5	16–18	−4. 0
4–6	12. 5	18–20	−7. 5
6–8	11. 0	20–22	−11. 0
8–10	9. 5	22–24	−14. 5
10–12	7. 0	24–24. 2	−17. 5
12–14	+3. 0		

Sum of the mean temperatures of the intervals 0–24,000 feet	+47. 0
Mean temperature of air column below 24,000 feet, in °C$=\frac{47.0}{12}$	+3. 9
Mean temperature of air column below 24,200 feet=+3.9, in °C$-\frac{0.2\times 17.5}{24.2}$	+3. 8
Altitude corresponding to 12.22 in. Hg. (Table II)	22, 775
Altitude corresponding to 29.54 in. Hg. (Table II)	+354
Standard altitude, in feet	22, 421
Temperature correction corresponding to +3.8° C. and 22,421 feet (Table IV)	+986
Actual altitude above surface	23, 407
Elevation of ground surface	+800
Actual altitude above sea level, in feet	24, 207

REFERENCES

1. Bureau of Standards: "Altitude-Pressure Tables." Aeronautic Instruments Circular No. 3, Third Edition, 1920.

2. Toussaint, A.: "Study of the Performance of an Airplane Fitted with a Supercharged Engine." L'Aeronautique, October, 1919.

3. Gregg, W. R.: "Standard Atmosphere." N. A. C. A. Technical Report No. 147, 1922. See this reference for comparison of the standard temperatures and observed temperatures.

4. Brombacher, W. G.: "The Determination of Altitude of Aircraft." Journal of the Optical Society of America and Review of Scientific Instruments, page 739, volume 7, 1923.

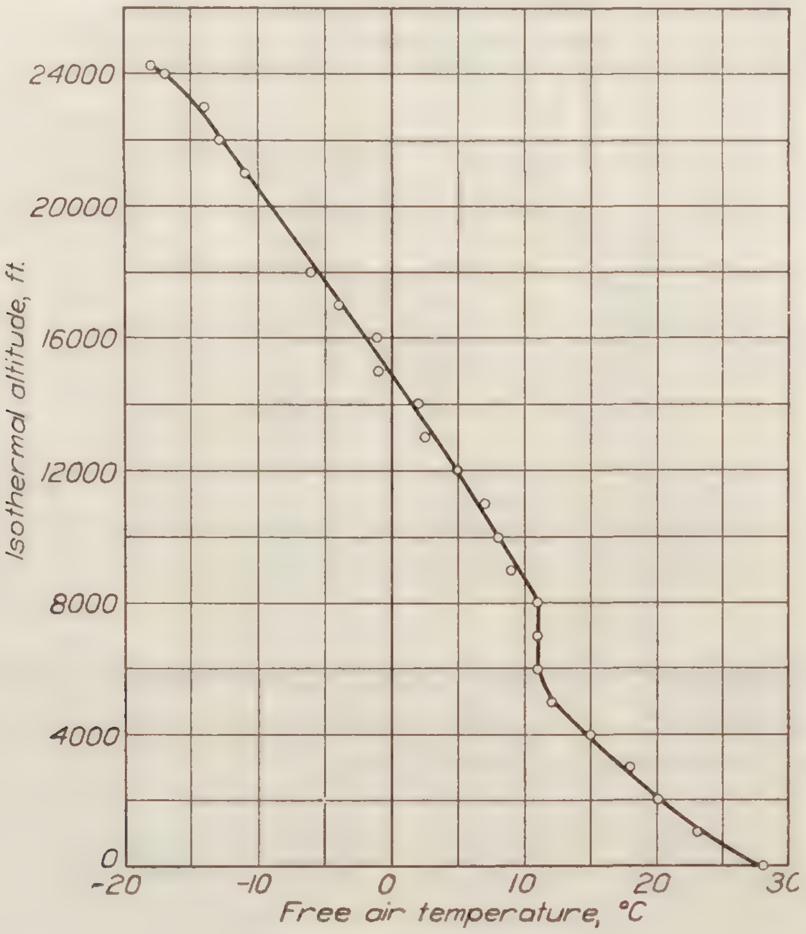


FIG. 1

5. Aeronautic Instruments Section, Bureau of Standards: "Aircraft Instruments." The Ronald Press Co., New York, 1926.

TABLE I

ALTITUDE-PRESSURE TABLE—FEET-MILLIMETERS

p mm.	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
87	50073	50049	50025	50001	49977	49953	49929	49905	49881	49857
88	49833	49810	49786	49762	738	715	691	667	644	620
89	596	573	550	526	503	479	456	433	409	386
90	362	339	316	293	270	247	49223	49200	49177	49154
91	49131	49108	49085	49062	49039	49016	48994	48971	48948	48925
92	48902	48879	48857	48834	48812	48789	766	744	721	698
93	676	653	631	609	586	564	541	519	497	474
94	452	430	407	385	363	341	319	297	275	252
95	230	48208	48186	48164	48143	48121	48099	48077	48055	48033
96	48011	47989	47968	47946	47924	47902	47881	47859	47837	47816
97	47794	773	751	730	708	687	665	644	622	601
98	579	558	537	516	494	473	452	431	409	388
99	367	346	325	304	283	262	241	220	47199	47178

TABLE I—Continued

ALTITUDE-PRESSURE TABLE—FEET-MILLIMETERS—Continued

p mm.	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
100	47156	47136	47115	47094	47073	47052	47032	47011	46990	46969
101	46948	46928	46907	46886	46866	46845	46824	46804	783	763
102	742	721	701	681	660	640	619	599	579	558
103	538	517	497	477	457	436	416	396	376	355
104	335	315	295	275	255	235	215	46195	46175	46155
105	46135	46115	46095	46075	46055	46036	46016	45996	45976	45956
106	45936	45917	45897	45877	45858	45838	45819	799	779	760
107	740	721	701	682	662	643	623	604	584	565
108	545	526	507	487	468	449	430	410	391	372
109	352	333	314	295	276	257	238	218	199	45180
110	45161	45142	45123	45104	45085	45066	45047	45028	45010	44991
111	44972	44953	44934	44915	44896	44878	44859	44840	44821	803
112	784	765	747	728	709	691	672	654	635	616
113	598	579	561	542	524	506	487	469	450	432
114	413	395	377	358	340	322	304	285	267	249
115	230	212	194	44176	44158	44140	44122	44103	44085	44067
116	44049	44031	44013	43995	43977	43959	43941	43923	43905	43887
117	43869	43851	43834	816	798	780	762	744	727	709
118	691	673	656	638	620	603	585	567	550	532
119	514	497	479	462	444	427	409	392	374	357
120	339	322	304	287	270	252	235	217	200	183
121	43165	43148	43131	43113	43096	43079	43062	43044	43027	43010
122	42993	42976	42958	42941	42924	42907	42890	42873	42856	42839
123	822	805	788	771	754	737	720	703	686	669
124	652	635	618	602	585	568	551	534	517	501
125	484	467	450	434	417	400	384	367	350	334
126	317	300	284	267	251	234	218	201	184	168
127	42151	42135	42118	42102	42086	42069	42053	42036	42020	42004
128	41987	41971	41954	41938	41922	41906	41889	41873	41857	41840
129	824	808	792	776	759	743	727	711	695	679
130	662	646	630	614	598	582	566	550	534	518
131	502	486	470	454	438	422	406	390	375	359
132	343	327	311	295	279	264	248	232	216	200
133	185	169	41153	41138	41122	41106	41091	41075	41059	41043
134	41028	41012	40997	40981	40966	40950	40934	40919	40903	40888
135	40872	40857	841	826	811	795	780	764	749	733
136	718	703	687	672	657	641	626	611	595	580
137	565	549	534	519	504	488	473	458	443	428
138	412	397	382	367	352	337	322	307	292	276
139	261	246	231	216	201	186	171	156	40141	40126
140	40111	40096	40081	40067	40052	40037	40022	40007	39992	39977
141	39962	39947	39933	39918	39903	39888	39873	39859	844	829
142	814	800	785	770	755	741	726	711	697	682
143	667	653	638	623	609	594	580	565	550	536
144	521	507	492	478	463	449	434	420	405	391
145	376	362	348	333	319	304	290	276	261	247
146	232	218	204	190	175	161	147	39132	39118	39104
147	39090	39075	39061	39047	39033	39018	39004	38990	38976	38962
148	38948	38933	38919	38905	38891	38877	38863	849	835	821
149	806	792	778	764	750	736	722	708	694	680
150	666	652	639	625	611	597	583	569	555	541
151	527	514	500	486	472	458	444	431	417	403
152	389	376	362	348	334	321	307	293	280	266
153	252	238	225	211	198	184	170	157	143	38129
154	38116	38102	38089	38075	38062	38048	38035	38021	38007	37994
155	37980	37967	37953	37940	37927	37913	37900	37886	37873	859
156	846	832	819	806	792	779	765	752	739	725
157	712	699	685	672	659	646	632	619	606	592
158	579	566	553	539	526	513	500	487	473	460
159	447	434	421	408	394	381	368	355	342	329
160	316	303	290	276	263	250	237	224	211	198
161	185	172	159	146	133	37120	37107	37094	37081	37068
162	37056	37043	37030	37017	37004	36991	36978	36965	36952	36939
163	36927	36914	36901	36888	36875	863	850	837	824	811
164	799	786	773	760	748	735	722	710	697	684
165	671	659	646	633	621	608	596	583	570	558
166	545	532	520	507	495	482	469	457	444	432
167	419	407	394	382	369	357	344	332	319	307
168	294	282	269	257	245	232	220	207	195	183
169	170	158	145	133	36121	36108	36096	36084	36071	36059

TABLE I—Continued

ALTITUDE-PRESSURE TABLE—FEET-MILLIMETERS—Continued

p mm.	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
170	36046	36034	36022	36010	35997	35985	35973	35961	35948	35936
171	35924	35911	35899	35887	875	862	850	838	826	814
172	801	789	777	765	753	741	728	716	704	692
173	680	668	656	644	632	620	607	595	583	571
174	559	547	535	523	511	499	487	475	463	451
175	439	427	415	403	391	379	367	356	344	332
176	320	308	296	284	272	260	248	237	225	213
177	201	189	177	165	154	142	130	118	35106	35095
178	35083	35071	35059	35048	35036	35024	35012	35000	34989	34977
179	34965	34954	34942	34930	34918	34907	34895	34883	872	860
180	848	837	825	813	802	790	778	767	755	743
181	732	720	708	697	685	674	662	650	639	627
182	616	604	592	581	569	558	546	535	523	511
183	500	488	477	465	454	442	431	419	408	396
184	385	373	362	351	339	328	316	305	293	282
185	270	259	248	236	225	213	202	190	179	168
186	156	145	134	122	34111	34099	34088	34077	34065	34054
187	34043	34031	34020	34009	33997	33986	33975	33964	33952	33941
188	33930	33918	33907	33896	885	873	862	851	840	828
189	817	806	795	783	772	761	750	739	727	716
190	705	694	683	671	660	649	638	627	616	604
191	593	582	571	560	549	538	527	516	504	493
192	482	471	460	449	438	427	416	405	394	383
193	372	361	350	339	328	317	306	294	283	272
194	261	250	239	228	218	207	196	185	174	163
195	152	141	130	119	33108	33097	33086	33075	33064	33054
196	33043	33032	33021	33010	32999	32988	32977	32966	32956	32945
197	32934	32923	32912	32901	890	880	869	858	847	836
198	825	815	804	793	782	771	761	750	739	728
199	717	707	696	685	674	664	653	642	631	621

p mm.	0	0.2	0.4	0.6	0.8	*p* mm.	0	0.2	0.4	0.6	0.8
200	32610	32588	32567	32546	32524	230	29571	29552	29533	29514	29495
201	503	482	460	439	418	231	476	457	438	419	400
202	396	375	354	332	311	232	380	361	342	323	304
203	290	269	248	226	205	233	285	267	248	229	210
204	184	163	142	121	32100	234	191	171	153	134	115
205	32079	32058	32037	32016	31995	235	096	29077	29059	29040	29021
206	31974	31953	31932	31911	890	236	29002	28983	28965	28946	28927
207	869	848	828	807	786	237	28909	890	871	853	834
208	765	744	724	703	682	238	815	797	778	760	741
209	661	641	620	599	579	239	722	704	685	667	648
210	558	538	517	496	476	240	630	611	593	574	556
211	455	435	414	394	373	241	537	519	500	482	464
212	353	332	312	292	271	242	445	427	408	390	372
213	251	230	210	190	169	243	353	335	317	298	280
214	149	129	109	31088	31068	244	262	244	225	207	189
215	31048	31028	31007	30987	30967	245	171	153	134	116	098
216	30947	30927	30907	886	866	246	28080	28062	28044	28026	28008
217	846	826	806	786	766	247	27989	27971	27953	27935	27917
218	746	726	706	686	666	248	899	881	863	845	827
219	646	626	606	586	567	249	809	791	773	755	737
220	547	527	507	487	467	250	719	702	684	666	648
221	447	428	408	388	368	251	630	612	594	576	559
222	349	329	309	290	270	252	541	523	505	487	470
223	250	231	211	191	172	253	452	434	416	399	381
224	152	133	113	30093	30074	254	363	346	328	310	293
225	30054	30035	30015	29996	29976	255	275	257	240	222	204
226	29957	29938	29918	899	879	256	187	169	152	134	111
227	860	841	821	802	783	257	099	27082	27064	27047	27029
228	763	744	725	706	687	258	27012	26994	26977	26959	26942
229	667	648	629	610	590	259	26924	907	890	872	855

TABLE I—Continued

ALTITUDE-PRESSURE TABLE—FEET-MILLIMETERS—Continued

p mm.	0	0.2	0.4	0.6	0.8	*p* mm.	0	0.2	0.4	0.6	0.8
260	26838	26820	26803	26786	26768	330	21337	21323	21308	21294	21280
261	751	734	716	699	682	331	266	251	237	223	209
262	665	647	630	613	596	332	194	180	166	152	138
263	579	561	544	527	510	333	123	109	095	081	21067
264	493	476	458	441	424	334	21052	21038	21024	21010	20996
265	407	390	373	356	339	335	20982	20968	20953	20939	925
266	322	305	288	271	254	336	911	897	883	869	855
267	237	220	203	186	169	337	841	827	813	799	784
268	152	135	118	102	085	338	770	756	742	728	714
269	26068	26051	26034	26017	26000	339	700	686	672	658	644
270	25984	25967	25950	25933	25916	340	630	616	603	589	575
271	900	883	866	849	833	341	561	547	533	519	505
272	816	799	782	766	749	342	491	477	463	450	436
273	732	716	699	682	666	343	422	408	394	380	366
274	649	632	616	599	583	344	352	339	325	311	297
275	566	550	533	516	500	345	283	270	256	242	228
276	483	467	450	434	417	346	215	201	187	173	160
277	401	384	368	351	335	347	146	132	118	105	091
278	318	302	286	269	253	348	077	20064	20050	20036	20023
279	236	220	204	187	171	349	20009	19995	19982	19968	19954
280	154	138	122	106	089	350	19941	927	913	900	886
281	25073	25057	25040	25024	25008	351	872	859	845	832	818
282	24992	24975	24959	24943	24927	352	804	791	777	764	750
283	911	894	878	862	846	353	737	723	701	696	683
284	830	813	797	781	765	354	669	656	642	629	615
285	749	733	717	701	685	355	602	588	575	561	548
286	669	653	637	620	604	356	534	521	507	494	481
287	588	572	556	540	524	357	467	454	440	427	413
288	509	493	477	461	445	358	400	387	373	360	346
289	429	413	397	381	365	359	333	320	306	293	280
290	349	334	318	302	286	360	266	253	240	226	213
291	270	254	238	223	207	361	200	186	173	160	147
292	191	175	159	144	128	362	133	120	107	094	080
293	112	096	081	24065	24049	363	067	19054	19041	19027	19014
294	24033	24018	24002	23986	23971	364	19001	18988	18974	18961	18948
295	23955	23939	23924	908	892	365	18935	922	909	895	882
296	877	861	845	830	814	366	869	856	843	830	817
297	799	783	768	752	737	367	803	790	777	764	751
298	721	706	690	674	659	368	738	725	712	699	685
299	643	628	612	597	581	369	672	659	646	633	620
300	566	551	535	520	504	370	607	594	581	568	555
301	489	473	458	443	427	371	542	529	516	503	490
302	412	397	381	366	351	372	477	464	451	438	425
303	335	320	305	289	274	373	412	399	386	373	361
304	259	243	228	213	198	374	348	335	322	309	296
305	182	167	152	137	122	375	283	270	257	244	232
306	106	091	076	23061	23046	376	219	206	193	180	167
307	23031	23015	23000	22985	22970	377	154	141	129	116	103
308	22955	22940	22925	909	894	378	090	077	065	18052	18039
309	879	864	849	834	819	379	18026	18013	18001	17988	17975
310	804	789	774	759	744	380	17962	17950	17937	924	911
311	729	714	699	684	669	381	899	886	873	860	848
312	654	639	624	609	594	382	835	822	810	797	784
313	579	564	546	534	519	383	772	759	746	734	721
314	504	490	475	460	445	384	708	696	683	670	658
315	430	415	400	385	371	385	645	632	620	607	595
316	356	341	326	311	296	386	582	569	557	544	532
317	282	267	252	237	223	387	519	507	494	481	469
318	208	193	178	164	149	388	456	444	431	419	406
319	134	120	105	090	076	389	394	381	369	356	344
320	22061	22046	22032	22017	22002	390	331	319	306	294	281
321	21988	21973	21959	21944	21929	391	269	256	244	231	219
322	915	900	886	871	856	392	206	194	182	169	157
323	842	827	813	798	784	393	144	132	119	107	095
324	769	755	740	726	711	394	082	070	17057	17045	17033
325	697	682	668	653	639	395	17020	17008	16996	16983	16971
326	625	610	596	581	567	396	16958	16946	934	921	909
327	552	538	524	509	495	397	897	885	872	860	848
328	481	466	452	437	423	398	835	823	811	798	786
329	409	394	380	366	351	399	774	762	749	737	725

TABLE I—Continued

ALTITUDE-PRESSURE TABLE—FEET-MILLIMETERS—Continued

p mm.	0	0.2	0.4	0.6	0.8	*p* mm.	0	0.2	0.4	0.6	0.8
400	16713	16700	16688	16676	16664	470	12704	12693	12682	12671	12661
401	652	639	627	615	603	471	650	639	629	618	607
402	591	578	566	554	542	472	596	586	575	564	554
403	530	518	505	493	481	473	543	532	522	511	500
404	469	457	445	432	420	474	490	479	468	458	447
405	408	396	384	372	360	475	436	426	415	404	394
406	348	336	324	312	299	476	383	372	362	351	341
407	287	275	263	251	239	477	330	319	309	298	288
408	227	215	203	191	179	478	277	266	256	245	235
409	167	155	143	131	119	479	224	213	203	192	182
410	107	095	083	071	16059	480	171	161	150	140	129
411	16047	16035	16023	16011	15999	481	118	108	097	087	076
412	15987	15975	15963	15951	940	482	066	055	12045	12034	12024
413	928	916	904	892	880	483	12013	12003	11992	11982	11971
414	868	856	844	832	820	484	11961	11950	940	929	919
415	809	797	785	773	761	485	908	898	887	877	866
416	749	737	725	714	702	486	856	845	835	825	814
417	690	678	666	654	643	487	804	793	783	772	762
418	631	619	607	595	584	488	752	741	731	720	710
419	572	560	548	536	525	489	700	689	679	668	658
420	513	501	489	478	466	490	648	637	627	616	606
421	454	442	431	419	407	491	596	585	575	565	554
422	395	384	372	360	348	492	544	534	523	513	503
423	337	325	313	302	290	493	492	482	472	461	451
424	278	267	255	243	232	494	441	430	420	410	399
425	220	208	197	185	174	495	389	379	368	358	348
426	162	150	139	127	115	496	337	327	317	307	296
427	104	092	081	069	057	497	286	276	266	255	245
428	15046	15034	15023	15011	15000	498	235	225	214	204	194
429	14988	14976	14965	14953	14942	499	184	173	163	153	143
430	930	919	907	896	884	500	132	122	112	102	092
431	872	861	849	838	826	501	081	071	061	051	11041
432	815	803	792	780	769	502	11030	11020	11010	11000	10990
433	757	746	735	723	711	503	10980	10969	10959	10949	939
434	700	689	679	666	654	504	929	919	909	898	888
435	643	631	620	609	597	505	878	868	858	848	838
436	586	574	563	552	540	506	827	817	807	797	787
437	529	517	506	495	483	507	777	767	757	747	736
438	472	460	449	438	426	508	726	716	706	696	687
439	415	404	392	381	370	509	676	666	656	646	636
440	358	347	336	324	313	510	626	616	606	596	586
441	302	290	279	268	256	511	576	565	555	545	535
442	245	234	223	211	200	512	525	515	505	495	485
443	189	178	166	155	144	513	475	465	455	445	435
444	132	121	110	099	088	514	425	415	405	395	385
445	076	065	14054	14043	14031	515	375	365	355	345	336
446	14020	14009	13998	13987	13975	516	326	316	306	296	286
447	13964	13953	942	931	920	517	276	266	256	246	236
448	908	897	886	875	864	518	226	216	206	196	186
449	853	841	830	819	808	519	176	167	157	147	137
450	13797	786	775	763	752	520	127	117	107	097	087
451	741	730	719	708	697	521	078	068	058	10048	10038
452	686	675	664	653	641	522	10028	10018	10008	9999	9989
453	630	619	608	597	586	523	9979	9969	9959	9949	9940
454	575	564	553	542	531	524	9930	9920	9910	9900	9890
455	520	509	498	487	476	525	9881	9871	9861	9851	9841
456	465	454	443	432	421	526	9831	9822	9812	9802	9792
457	410	399	388	377	366	527	9782	9773	9763	9753	9743
458	355	344	333	322	311	528	9734	9724	9714	9704	9695
459	300	289	278	267	256	529	9685	9675	9665	9656	9646
460	245	234	224	213	202	530	9636	9626	9617	9607	9597
461	191	180	169	158	147	531	9587	9578	9568	9558	9548
462	136	125	115	104	093	532	9539	9529	9519	9510	9500
463	082	071	060	13049	13039	533	9490	9480	9471	9461	9451
464	13028	13017	13006	12995	12984	534	9442	9432	9422	9413	9403
465	12974	12963	12952	941	930	535	9393	9384	9374	9364	9355
466	919	908	898	887	876	536	9345	9335	9326	9316	9306
467	865	854	844	833	822	537	9297	9287	9277	9268	9258
468	811	801	790	779	768	538	9248	9239	9229	9220	9210
469	758	747	736	725	714	539	9200	9191	9181	9172	9162

TABLE I—Continued

ALTITUDE-PRESSURE TABLE—FEET-MILLIMETERS—Continued

p mm.	0	0.2	0.4	0.6	0.8	*p* mm.	0	0.2	0.4	0.6	0.8
540	9152	9143	9133	9124	9114	610	5956	5947	5939	5930	5921
541	9104	9095	9085	9076	9066	611	5913	5904	5895	5887	5878
542	9056	9047	9037	9028	9018	612	5869	5861	5852	5843	5835
543	9009	8999	8990	8980	8970	613	5826	5817	5809	5800	5791
544	8961	8951	8942	8932	8923	614	5783	5774	5765	5757	5748
545	8913	8904	8894	8885	8875	615	5739	5731	5722	5713	5705
546	8866	8856	8847	8837	8828	616	5696	5687	5679	5670	5662
547	8818	8809	8799	8790	8780	617	5653	5644	5636	5627	5619
548	8771	8761	8752	8742	8733	618	5610	5601	5593	5584	5576
549	8723	8714	8704	8695	8685	619	5567	5558	5550	5541	5533
550	8676	8666	8657	8647	8638	620	5524	5515	5507	5498	5490
551	8629	8619	8610	8600	8591	621	5481	5473	5464	5455	5447
552	8581	8572	8563	8553	8544	622	5438	5430	5421	5413	5404
553	8534	8525	8516	8506	8497	623	5396	5387	5378	5370	5361
554	8487	8478	8468	8459	8450	624	5353	5344	5336	5327	5319
555	8440	8431	8422	8412	8403	625	5310	5302	5293	5285	5276
556	8393	8384	8375	8365	8356	626	5267	5259	5250	5242	5233
557	8347	8337	8328	8318	8309	627	5225	5216	5208	5199	5191
558	8300	8290	8281	8272	8262	628	5182	5174	5165	5157	5148
559	8253	8244	8234	8225	8216	629	5140	5132	5123	5115	5106
560	8206	8197	8188	8178	8169	630	5098	5089	5081	5072	5064
561	8160	8150	8141	8132	8123	631	5055	5047	5038	5030	5021
562	8113	8104	8095	8085	8076	632	5013	5005	4996	4988	4979
563	8067	8058	8048	8039	8030	633	4971	4962	4954	4945	4937
564	8020	8011	8002	7993	7983	634	4929	4920	4912	4903	4895
565	7974	7965	7956	7946	7937	635	4886	4878	4870	4861	4853
566	7928	7919	7910	7900	7891	636	4844	4836	4828	4819	4811
567	7882	7873	7863	7854	7845	637	4802	4794	4786	4777	4769
568	7836	7826	7817	7808	7799	638	4760	4752	4744	4735	4727
569	7790	7780	7771	7762	7753	639	4718	4710	4702	4693	4685
570	7744	7734	7725	7716	7707	640	4677	4668	4660	4652	4643
571	7698	7689	7679	7670	7661	641	4635	4626	4618	4610	4601
572	7652	7643	7634	7624	7615	642	4593	4585	4576	4568	4560
573	7606	7597	7588	7579	7570	643	4551	4543	4535	4526	4518
574	7560	7551	7542	7533	7524	644	4510	4501	4493	4485	4476
575	7515	7506	7497	7487	7478	645	4468	4460	4452	4443	4435
576	7469	7460	7451	7442	7433	646	4427	4418	4410	4402	4393
577	7424	7415	7405	7396	7387	647	4385	4377	4369	4360	4352
578	7378	7369	7360	7351	7342	648	4344	4335	4327	4319	4311
579	7333	7324	7315	7306	7296	649	4302	4294	4286	4278	4269
580	7287	7278	7269	7260	7251	650	4261	4253	4244	4236	4228
581	7242	7233	7224	7215	7206	651	4220	4211	4203	4195	4187
582	7197	7188	7179	7170	7161	652	4178	4170	4162	4154	4146
583	7152	7143	7134	7125	7116	653	4137	4129	4121	4113	4104
584	7107	7098	7089	7080	7071	654	4096	4088	4080	4072	4063
585	7062	7053	7044	7035	7026	655	4055	4047	4039	4030	4022
586	7017	7008	6999	6990	6981	656	4014	4006	3998	3990	3981
587	6972	6963	6954	6945	6936	657	3973	3965	3957	3949	3940
588	6927	6918	6909	6900	6891	658	3932	3924	3916	3908	3899
589	6882	6873	6864	6855	6847	659	3891	3883	3875	3867	3859
590	6838	6829	6820	6811	6802	660	3850	3842	3834	3826	3818
591	6793	6784	6775	6766	6757	661	3810	3802	3793	3785	3777
592	6748	6739	6730	6722	6713	662	3769	3761	3753	3745	3736
593	6704	6695	6686	6677	6668	663	3728	3720	3712	3704	3696
594	6659	6650	6642	6633	6624	664	3688	3680	3671	3663	3655
595	6615	6606	6597	6588	6579	665	3647	3639	3631	3623	3615
596	6571	6562	6553	6544	6535	666	3607	3598	3590	3582	3574
597	6526	6517	6509	6500	6491	667	3566	3558	3550	3542	3534
598	6482	6473	6464	6456	6447	668	3526	3518	3509	3501	3493
599	6438	6429	6420	6411	6403	669	3485	3477	3469	3461	3453
600	6394	6385	6376	6367	6359	670	3445	3437	3429	3421	3413
601	6350	6341	6332	6323	6315	671	3405	3397	3389	3381	3372
602	6306	6297	6288	6279	6271	672	3364	3356	3348	3340	3332
603	6262	6253	6244	6236	6227	673	3324	3316	3308	3300	3292
604	6218	6209	6200	6192	6183	674	3284	3276	3268	3260	3252
605	6174	6165	6157	6148	6139	675	3244	3236	3228	3220	3212
606	6130	6122	6113	6104	6096	676	3204	3196	3188	3180	3172
607	6087	6078	6069	6061	6052	677	3164	3156	3148	3140	3132
608	6043	6034	6026	6017	6008	678	3124	3116	3108	3100	3092
609	6000	5991	5982	5974	5965	679	3084	3076	3068	3060	3052

TABLE I—Continued

ALTITUDE-PRESSURE TABLE—FEET-MILLIMETERS—Continued

p mm.	0	0.2	0.4	0.6	0.8	p mm.	0	0.2	0.4	0.6	0.8
680	3044	3036	3028	3020	3012	740	736	728	721	714	706
681	3004	2996	2989	2981	2973	741	699	691	684	676	669
682	2965	2957	2949	2941	2933	742	662	654	647	639	632
683	2925	2917	2909	2901	2893	743	624	617	610	602	595
684	2885	2877	2869	2862	2854	744	587	580	573	565	558
685	2846	2838	2830	2822	2814	745	550	543	536	528	521
686	2806	2798	2790	2782	2775	746	513	506	499	491	484
687	2767	2759	2751	2743	2735	747	476	469	462	454	447
688	2727	2719	2711	2704	2696	748	440	432	425	417	410
689	2688	2680	2672	2664	2656	749	403	395	388	381	373
690	2648	2640	2633	2625	2617	750	366	359	351	344	336
691	2609	2601	2593	2585	2578	751	329	322	314	307	300
692	2570	2562	2554	2546	2538	752	292	285	278	270	263
693	2531	2523	2515	2507	2499	753	256	248	241	234	226
694	2491	2483	2476	2468	2460	754	219	212	204	197	190
695	2452	2444	2437	2429	2421	755	182	175	168	161	153
696	2413	2405	2397	2390	2382	756	146	139	131	124	117
697	2374	2366	2358	2351	2343	757	109	102	95	87	80
698	2335	2327	2319	2312	2304	758	73	66	58	51	44
699	2296	2288	2280	2273	2265	759	36	29	22	15	7
700	2257	2249	2242	2234	2226	760	0	−7	−15	−22	−29
701	2218	2210	2203	2195	2187	761	−36	44	51	58	65
702	2179	2172	2164	2156	2148	762	−73	80	87	94	102
703	2141	2133	2125	2117	2110	763	−109	116	124	131	138
704	2102	2094	2086	2079	2071	764	−145	153	160	167	174
705	2063	2055	2048	2040	2032	765	−181	189	196	203	210
706	2024	2017	2009	2001	1994	766	−218	225	232	239	247
707	1986	1978	1970	1963	1955	767	−254	261	268	275	283
708	1947	1940	1932	1924	1916	768	−290	297	304	312	319
709	1909	1901	1893	1886	1878	769	−326	333	340	348	355
710	1870	1863	1855	1847	1840	770	−362	369	376	384	391
711	1832	1824	1817	1809	1801	771	−398	405	412	420	427
712	1793	1786	1778	1770	1763	772	−434	441	448	456	463
713	1755	1747	1740	1732	1724	773	−470	477	484	491	499
714	1717	1709	1702	1694	1686	774	−506	513	520	527	534
715	1679	1671	1663	1656	1648	775	−542	549	556	563	570
716	1640	1633	1625	1617	1610	776	−577	585	592	599	606
717	1602	1595	1587	1579	1572	777	−613	620	627	635	642
718	1564	1556	1549	1541	1534	778	−649	656	663	670	677
719	1526	1518	1511	1503	1496	779	−685	692	699	706	713
720	1488	1480	1473	1465	1458	780	−720	727	735	742	749
721	1450	1442	1435	1427	1420	781	−756	763	770	777	784
722	1412	1404	1397	1389	1382	782	−791	799	806	813	820
723	1374	1366	1359	1351	1344	783	−827	834	841	848	855
724	1336	1329	1321	1313	1306	784	−863	870	877	884	891
725	1298	1291	1283	1276	1268	785	−898	905	912	919	926
726	1261	1253	1245	1238	1230	786	−933	941	948	955	962
727	1223	1215	1208	1200	1193	787	−969	976	983	990	997
728	1185	1178	1170	1162	1155	788	−1004	011	018	025	032
729	1147	1140	1132	1125	1117	789	−1040	1047	1054	1061	1068
730	1110	1102	1095	1087	1080	790	−1075				
731	1072	1065	1057	1050	1042						
732	1035	1027	1020	1012	1005						
733	997	990	982	975	967						
734	960	952	945	937	930						
735	922	915	907	900	892						
736	885	877	870	863	855						
737	848	840	833	825	818						
738	810	803	795	788	780						
739	773	766	758	751	743						

TABLE II

ALTITUDE-PRESSURE TABLE—FEET-INCHES

p inches	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
3. 4	50228	50167	50104	50044	49982	49922	49862	49801	49741	49680
3. 5	49620	49561	49501	49442	49382	49323	49264	49206	49147	49089
3. 6	49030	48972	48915	48857	48799	48741	48684	48627	48570	48513
3. 7	48456	48400	48344	48288	48232	48175	48120	48065	48009	47954
3. 8	47898	47843	47789	47734	47679	47624	47570	47516	47462	47408
3. 9	47354	47301	47248	47194	47141	47088	47035	46982	46930	46877
4. 0	46824	46772	46720	46668	46616	46564	46513	46461	46410	463 8
4. 1	46307	46256	46206	46155	46104	46053	46003	45953	45903	45853
4. 2	45803	45753	45704	45654	45605	45555	45506	45458	45408	45359
4. 3	45310	45262	45213	45165	45117	45068	45020	44973	44925	44877
4. 4	44829	44782	44734	44687	44640	44592	44546	44499	44452	44405
4. 5	44358	44312	44266	44220	44173	44127	44081	44036	43990	43944
4. 6	43898	43853	43808	43762	43717	43672	43627	43582	43537	43492
4. 7	43448	43403	43359	43315	43270	43226	43182	43138	43094	43050
4. 8	43007	42963	42920	42876	42833	42790	42747	42704	42661	42618
4. 9	42575	532	490	447	42404	42362	42320	42278	42236	42193
5. 0	42151	42110	42068	42026	41985	41943	41902	41861	41819	41778
5. 1	41737	41696	41655	41614	573	532	492	451	411	41370
5. 2	41330	41290	41250	41210	41170	41130	41090	41050	41011	40971
5. 3	40931	40892	40853	40813	40774	40735	40696	40657	40618	579
5. 4	540	502	463	425	386	40347	40309	40271	40233	40195
5. 5	40156	40118	40080	40043	40005	39967	39929	39892	39854	39816
5. 6	39779	39742	39704	39667	39630	593	556	519	482	445
5. 7	408	372	39335	39298	39262	39225	39189	39153	39117	39080
5. 8	39044	39008	38972	38936	38900	38864	38829	38793	38757	38722
5. 9	38686	38651	615	580	545	509	474	439	404	369
6. 0	38343	38300	38265	38230	38200	38161	38126	38092	38057	38023
6. 1	37989	37954	37920	37886	37852	37818	37784	37750	37716	37682
6. 2	648	615	581	547	514	480	447	413	380	346
6. 3	37313	37280	37247	37214	37181	37147	37115	37082	37049	37016
6. 4	36983	36951	36918	36886	36853	36820	36788	36756	36723	36691
6. 5	659	627	595	563	531	498	467	435	403	371
6. 6	339	36308	36276	36245	36213	36181	36150	36119	36087	36056
6. 7	36024	35993	35962	35931	35900	35869	35838	35807	35776	35745
6. 8	35714	683	653	622	591	560	530	499	469	438
6. 9	408	378	347	317	35287	35257	35227	35197	35167	35136
7. 0	35106	35077	35047	35017	34987	34957	34927	34898	34868	34838
7. 1	34809	34779	34749	34720	690	661	631	602	573	543
7. 2	514	485	455	426	397	368	339	310	34281	34251
7. 3	34222	34194	34165	34136	34107	34078	34049	34020	33992	33963
7. 4	33934	33906	33877	33848	33820	33791	33763	33734	706	678
7. 5	649	621	593	564	536	508	480	452	424	395
7. 6	367	339	311	283	33255	33227	33200	33172	33144	33116
7. 7	33088	33061	33033	33005	32978	32950	32922	32895	32867	32840
7. 8	32812	32785	32758	32730	703	676	648	621	594	567
7. 9	539	512	485	458	431	404	377	350	323	296
8. 0	269	32242	32215	32188	32161	32135	32108	32081	32054	32028
8. 1	32001	31975	31948	31921	31895	31868	31842	31815	31789	31763
8. 2	31736	710	684	657	631	605	578	552	526	500
8. 3	474	448	422	396	370	344	318	292	266	31240
8. 4	31214	31188	31163	31137	31111	31085	31060	31034	31008	30983
8. 5	30957	30931	30906	30880	30855	30829	30804	30778	30753	728
8. 6	702	677	652	626	601	576	550	525	500	475
8. 7	449	424	399	374	349	324	299	274	249	30224
8. 8	30199	30174	30149	30125	30100	30075	30050	30025	30001	29976
8. 9	29951	29927	29902	29877	29853	29828	29804	29779	29755	730
9. 0	706	681	657	633	608	584	560	535	511	487
9. 1	462	438	414	390	366	342	317	293	269	245
9. 2	29221	29197	29173	29149	29125	29101	29077	29053	29029	29005
9. 3	28982	28958	28934	28910	28887	28863	28839	28816	28792	28768
9. 4	745	721	698	674	650	627	603	580	556	533
9. 5	510	486	463	439	416	393	369	346	323	300
9. 6	276	253	230	28207	28184	28161	28138	28115	28092	28069
9. 7	28046	28023	28000	27977	27954	27931	27908	27885	27862	27839
9. 8	27816	27794	27771	748	725	702	680	657	634	612
9. 9	589	566	544	521	499	476	453	431	408	386

TABLE II—Continued

ALTITUDE-PRESSURE TABLE—FEET-INCHES—Continued

p inches	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
10. 0	27363	27341	27318	27296	27274	27251	27229	27206	27184	27162
10. 1	27140	27117	27095	27073	27050	27028	27006	26984	26962	26940
10. 2	26917	26895	26873	26851	26829	26807	26785	763	741	719
10. 3	697	676	654	632	610	588	566	544	523	501
10. 4	479	457	436	414	392	371	349	327	306	284
10. 5	262	241	219	26198	26176	26155	26133	26112	26090	26069
10. 6	26048	26026	26005	25984	25962	25941	25919	25898	25877	25856
10. 7	25834	25813	25792	771	749	728	707	686	665	644
10. 8	622	601	580	559	538	517	496	475	454	433
10. 9	412	391	370	350	329	308	287	266	245	224
11. 0	25204	25183	25162	25141	25121	25100	25079	25059	25038	25017
11. 1	24996	24976	24955	24935	24914	24894	24873	24852	24832	24811
11. 2	791	770	750	730	709	689	668	648	628	607
11. 3	587	567	546	526	506	486	465	445	425	405
11. 4	384	364	344	324	304	284	263	243	223	203
11. 5	24183	24163	24143	24123	24103	24083	24063	24043	24023	24003
11. 6	23983	23963	23944	23924	23904	23884	23864	23844	23824	23805
11. 7	785	765	745	726	706	686	666	647	627	607
11. 8	588	568	549	529	509	490	470	451	431	412
11. 9	392	373	353	334	314	295	275	256	237	217
12. 0	198	23178	23159	23140	23121	23101	23082	23063	23043	23024
12. 1	23005	22986	22966	22947	22928	22909	22890	22870	22851	22832
12. 2	22813	794	775	756	737	718	698	679	660	641
12. 3	622	603	584	565	547	528	509	490	471	452
12. 4	433	414	395	377	358	339	320	301	282	264
12. 5	245	226	207	189	22170	22151	22133	22114	22095	22077
12. 6	22058	22040	22021	22002	21984	21965	21947	21928	21910	21891
12. 7	21872	21854	21836	21817	799	780	762	743	725	706
12. 8	688	670	651	633	615	596	578	560	542	523
12. 9	505	487	469	450	432	414	396	377	359	341
13. 0	323	305	287	268	250	232	214	196	21178	21160
13. 1	21142	21124	21106	21088	21070	21052	21034	21016	20998	20980
13. 2	20962	20944	20926	20908	20890	20873	20855	20837	819	801
13. 3	783	765	748	730	712	694	677	659	641	623
13. 4	605	588	570	552	535	517	499	482	464	446
13. 5	429	411	394	376	358	341	323	306	288	271
13. 6	253	236	218	201	183	20166	20149	20131	20114	20096
13. 7	20079	20061	20044	20027	20009	19992	19975	19957	19940	19922
13. 8	19905	19888	19871	19853	19836	819	802	784	767	750
13. 9	733	715	698	681	664	647	630	613	595	578
14. 0	561	544	527	510	493	476	459	442	425	408
14. 1	391	374	357	340	323	306	289	272	255	238
14. 2	221	204	187	170	19154	19137	19120	19103	19086	19069
14. 3	19052	19036	19019	19002	18985	18969	18952	18935	18918	18902
14. 4	18885	18868	18852	18835	818	802	785	768	752	735
14. 5	718	702	685	668	652	635	619	602	586	569
14. 6	553	536	520	503	487	470	454	437	421	404
14. 7	388	371	355	339	322	306	289	273	257	240
14. 8	224	208	191	175	18159	18142	18126	18110	18093	18077
14. 9	18061	18045	18028	18012	17996	17980	17963	17947	17931	17915
15. 0	17899	17882	17866	17850	834	818	802	786	770	754
15. 1	737	721	705	689	673	657	641	625	609	593
15. 2	577	561	545	529	513	497	481	465	449	433
15. 3	417	402	386	370	354	338	322	306	290	275
15. 4	259	243	227	211	196	180	164	17148	17132	17117
15. 5	17101	17085	17069	17054	17038	17022	17007	16991	16975	16959
15. 6	16944	16928	16912	16897	16881	16866	16850	834	819	803
15. 7	787	772	756	741	725	710	694	679	663	648
15. 8	632	617	601	586	570	555	539	524	508	493
15. 9	477	462	447	431	416	400	385	370	354	339
16. 0	324	308	293	278	262	247	232	216	201	186
16. 1	171	155	16140	16125	16110	16094	16079	16064	16049	16034
16. 2	16018	16003	15988	15973	15958	15943	15927	15912	15897	15882
16. 3	15867	15852	837	822	806	791	776	761	746	731
16. 4	716	701	686	671	656	641	626	611	596	581
16. 5	566	551	536	521	506	491	476	461	446	431
16. 6	416	402	387	372	357	342	327	312	298	283
16. 7	268	253	238	224	209	194	179	164	150	15135
16. 8	15120	15105	15091	15076	15061	15047	15032	15017	15002	14988
16. 9	14973	14958	14944	14929	14914	14900	14885	14870	14856	841

TABLE II—Continued

ALTITUDE-PRESSURE TABLE—FEET-INCHES—*Continued*

p inches	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
17. 0	14826	14812	14797	14783	14768	14753	14739	14724	14710	14695
17. 1	681	666	652	637	622	608	594	579	564	550
17. 2	536	521	507	492	478	463	449	434	420	406
17. 3	391	377	362	348	334	319	305	291	276	262
17. 4	247	233	219	204	190	176	162	147	14133	14119
17. 5	14104	14090	14076	14062	14047	14033	14019	14005	13990	13976
17. 6	13962	13948	13934	13919	13905	13891	13877	13863	849	834
17. 7	820	806	792	778	764	750	736	722	707	693
17. 8	679	665	651	637	623	609	595	581	567	553
17. 9	539	525	511	497	483	469	455	441	427	413
18. 0	399	385	371	357	343	329	315	301	287	274
18. 1	260	246	232	218	204	190	176	163	149	13135
18. 2	13121	13107	13094	13080	13066	13052	13038	13025	13011	12997
18. 3	12983	12970	12956	12942	12928	12915	12901	12887	12873	860
18. 4	846	832	819	805	791	778	764	750	736	723
18. 5	709	695	682	668	655	641	627	614	600	587
18. 6	573	559	546	532	519	505	492	478	464	451
18. 7	437	424	410	397	383	370	356	343	329	316
18. 8	302	289	275	262	249	235	222	208	195	181
18. 9	168	155	141	12128	12114	12101	12088	12074	12061	12048
19. 0	12034	12021	12008	11994	11981	11968	11954	11941	11928	11914
19. 1	11901	11888	11874	861	848	835	821	808	795	781
19. 2	768	755	742	729	715	702	689	676	663	649
19. 3	636	623	610	597	584	570	557	544	531	518
19. 4	505	491	478	465	452	439	426	413	400	387
19. 5	374	360	347	334	321	308	295	282	269	256
19. 6	243	230	217	204	191	178	165	152	139	11126
19. 7	11113	11100	11087	11074	11061	11048	11035	11023	11010	10997
19. 8	10984	10971	10958	10945	10932	10919	10906	10894	10881	868
19. 9	855	842	829	816	804	791	778	765	752	739
20. 0	726	714	701	688	675	662	650	637	624	611
20. 1	599	586	573	560	548	535	522	509	497	484
20. 2	471	459	446	433	421	408	395	383	370	357
20. 3	344	332	319	307	294	281	269	256	243	231
20. 4	218	206	193	180	168	155	143	130	10117	10105
20. 5	10092	10080	10067	10055	10042	10030	10017	10005	9992	9980
20. 6	9967	9955	9942	9930	9917	9905	9892	9880	9867	9855
20. 7	9842	9830	9817	9805	9793	9780	9768	9755	9743	9730
20. 8	9718	9706	9693	9681	9668	9656	9644	9631	9619	9607
20. 9	9594	9582	9570	9557	9545	9532	9520	9508	9495	9483
21. 0	9471	9458	9446	9434	9422	9409	9397	9385	9372	9360
21. 1	9348	9336	9323	9311	9299	9287	9274	9262	9250	9238
21. 2	9225	9213	9201	9189	9176	9164	9154	9140	9128	9116
21. 3	9103	9091	9079	9067	9055	9043	9030	9018	9006	8994
21. 4	8982	8970	8958	8946	8933	8921	8909	8897	8885	8873
21. 5	8861	8849	8837	8825	8813	8801	8789	8776	8764	8752
21. 6	8740	8728	8716	8704	8692	8680	8668	8656	8644	8632
21. 7	8620	8608	8596	8584	8572	8560	8548	8536	8524	8512
21. 8	8500	8489	8477	8465	8453	8441	8429	8417	8405	8393
21. 9	8381	8369	8357	8346	8334	8322	8310	8298	8286	8274
22. 0	8262	8250	8239	8227	8215	8203	8191	8179	8168	8156
22. 1	8144	8132	8120	8109	8097	8085	8073	8061	8050	8038
22. 2	8026	8014	8003	7991	7979	7967	7956	7944	7932	7920
22. 3	7909	7897	7885	7873	7862	7850	7838	7827	7815	7803
22. 4	7791	7780	7768	7756	7745	7733	7721	7710	7698	7686
22. 5	7675	7663	7652	7640	7628	7617	7605	7593	7582	7570
22. 6	7559	7547	7535	7524	7512	7501	7489	7478	7466	7454
22. 7	7443	7431	7420	7408	7397	7385	7374	7362	7350	7339
22. 8	7327	7316	7304	7293	7281	7270	7258	7247	7235	7224
22. 9	7212	7201	7189	7178	7167	7155	7144	7132	7121	7109
23. 0	7098	7086	7075	7064	7052	7041	7029	7018	7006	6995
23. 1	6984	6972	6961	6949	6938	6927	6915	6904	6893	6881
23. 2	6870	6858	6847	6836	6824	6813	6802	6790	6779	6768
23. 3	6756	6745	6734	6722	6711	6700	6688	6677	6666	6655
23. 4	6643	6632	6621	6610	6598	6587	6576	6564	6553	6542
23. 5	6531	6519	6508	6497	6486	6475	6463	6452	6441	6430
23. 6	6418	6407	6396	6385	6374	6363	6351	6340	6329	6318
23. 7	6307	6296	6284	6273	6262	6251	6240	6229	6218	6206
23. 8	6195	6184	6173	6162	6151	6140	6129	6118	6106	6095
23. 9	6084	6073	6062	6051	6040	6029	6018	6007	5996	5985

TABLE II—Continued

ALTITUDE-PRESSURE TABLE—FEET-INCHES—Continued

p inches	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
24. 0	5974	5962	5951	5940	5929	5918	5907	5896	5885	5874
24. 1	5863	5852	5841	5830	5819	5808	5797	5786	5775	5764
24. 2	5753	5742	5731	5720	5709	5698	5687	5676	5666	5655
24. 3	5644	5633	5622	5611	5600	5589	5578	5567	5555	5545
24. 4	5534	5524	5513	5502	5491	5480	5469	5458	5447	5436
24. 5	5425	5415	5404	5393	5382	5371	5360	5350	5339	5328
24. 6	5317	5306	5295	5285	5274	5263	5252	5241	5230	5220
24. 7	5209	5198	5187	5176	5166	5155	5144	5133	5123	5112
24. 8	5101	5090	5080	5069	5058	5047	5037	5026	5015	5004
24. 9	4994	4983	4972	4961	4951	4940	4929	4919	4908	4897
25. 0	4886	4876	4865	4854	4844	4833	4822	4812	4801	4790
25. 1	4780	4769	4758	4748	4737	4726	4716	4705	4695	4684
25. 2	4673	4663	4652	4642	4631	4620	4610	4599	4588	4578
25. 3	4567	4557	4546	4536	4525	4514	4504	4493	4483	4472
25. 4	4462	4451	4440	4430	4419	4409	4398	4388	4377	4367
25. 5	4356	4346	4335	4325	4314	4304	4293	4283	4272	4262
25. 6	4251	4241	4230	4220	4209	4199	4188	4178	4167	4157
25. 7	4146	4136	4125	4115	4105	4094	4084	4073	4063	4052
25. 8	4042	4032	4021	4011	4000	3990	3980	3969	3959	3948
25. 9	3938	3928	3917	3907	3896	3886	3876	3865	3855	3845
26. 0	3834	3824	3814	3803	3793	3782	3772	3762	3751	3741
26. 1	3731	3720	3710	3700	3689	3679	3669	3659	3648	3638
26. 2	3628	3617	3607	3597	3586	3576	3566	3556	3545	3535
26. 3	3525	3515	3504	3494	3484	3474	3463	3453	3443	3433
26. 4	3422	3412	3402	3392	3382	3371	3361	3351	3341	3331
26. 5	3320	3310	3300	3290	3279	3269	3259	3249	3239	3229
26. 6	3218	3208	3198	3188	3178	3168	3157	3147	3137	3127
26. 7	3117	3107	3097	3086	3076	3066	3056	3046	3036	3026
26. 8	3016	3005	2995	2985	2975	2965	2955	2945	2935	2925
26. 9	2915	2905	2895	2884	2874	2864	2854	2844	2834	2824
27. 0	2814	2804	2794	2784	2774	2764	2754	2744	2734	2724
27. 1	2714	2704	2694	2684	2674	2664	2654	2644	2634	2624
27. 2	2614	2604	2594	2584	2574	2564	2554	2544	2534	2524
27. 3	2514	2504	2494	2484	2474	2464	2454	2444	2434	2425
27. 4	2415	2405	2395	2385	2375	2365	2355	2345	2335	2325
27. 5	2315	2306	2296	2286	2276	2266	2256	2246	2236	2226
27. 6	2217	2207	2197	2187	2177	2167	2158	2148	2138	2128
27. 7	2118	2108	2098	2089	2079	2069	2059	2049	2040	2030
27. 8	2020	2010	2000	1990	1981	1971	1961	1951	1942	1932
27. 9	1922	1912	1902	1893	1883	1873	1863	1854	1844	1834
28. 0	1824	1814	1805	1795	1785	1776	1766	1756	1746	1737
28. 1	1727	1717	1707	1698	1688	1678	1668	1659	1649	1639
28. 2	1630	1620	1610	1601	1591	1581	1572	1562	1552	1542
28. 3	1533	1523	1513	1504	1494	1484	1475	1465	1456	1446
28. 4	1436	1427	1417	1407	1398	1388	1378	1369	1359	1350
28. 5	1340	1330	1321	1311	1302	1292	1282	1273	1263	1254
28. 6	1244	1234	1225	1215	1206	1196	1186	1177	1167	1158
28. 7	1148	1139	1129	1120	1110	1100	1091	1081	1072	1062
28. 8	1053	1043	1034	1024	1015	1005	995	986	976	967
28. 9	957	948	938	929	919	910	900	891	881	872
29. 0	863	853	844	834	825	815	806	796	787	777
29. 1	768	758	749	739	730	721	711	702	692	683
29. 2	673	664	655	645	636	626	617	607	598	589
29. 3	579	570	560	551	542	532	523	514	504	495
29. 4	485	476	467	457	448	439	429	420	410	401
29. 5	392	382	373	364	354	345	336	326	318	308
29. 6	298	289	280	270	261	252	242	233	224	215
29. 7	205	196	187	177	168	159	149	140	131	122
29. 8	112	103	94	85	75	66	57	47	38	29
29. 9	20	10	+1	−8	−17	−26	−36	−45	−54	−63

TABLE II—Continued

ALTITUDE-PRESSURE TABLE—FEET-INCHES—Continued

p inches	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
30. 0	−73	−82	−91	−100	−110	−119	−128	−137	−146	−156
30. 1	−165	174	183	192	202	211	220	229	238	248
30. 2	−257	266	275	284	293	303	312	321	330	339
30. 3	−348	358	367	376	385	394	403	412	421	431
30. 4	−440	449	458	467	476	485	494	504	513	522
30. 5	−531	540	549	558	567	576	585	594	604	613
30. 6	−622	631	640	649	658	667	676	685	694	703
30. 7	−712	721	730	740	749	758	767	776	785	794
30. 8	−803	812	821	830	839	848	857	866	875	884
30. 9	−893	902	911	920	929	938	947	956	965	974
31. 0	−983	992	1001	1010	1019	1028	1037	1046	1055	1064

TABLE III

ALTITUDE-PRESSURE-TEMPERATURE TABLE

Altitude, feet	Pressure		Temperature, °C.	Mean temperature, °C.	Isothermal altitude (+10° C.), feet
	in. Hg.	mm. Hg.			
−1000	31. 02	787. 9	+17. 0	+16. 0	−1010
−500	30. 47	773. 8	16. 0	15. 5	−510
0	29. 921	760. 0	15. 0	15. 0	−10
+500	29. 38	746. 4	14. 0	14. 5	+480
+1, 000	28. 86	732. 9	13. 0	14. 0	+980
1, 500	28. 33	719. 7	12. 0	13. 5	1, 480
2, 000	27. 82	706. 6	11. 0	13. 0	1, 980
2, 500	27. 31	693. 8	10. 0	12. 5	2, 470
3, 000	26. 81	681. 1	9. 1	12. 0	2, 980
3, 500	26. 32	668. 6	8. 1	11. 5	3, 480
4, 000	25. 84	656. 3	7. 1	11. 0	3, 990
4, 500	23. 36	644. 2	6. 1	10. 5	4, 500
5, 000	24. 89	632. 3	5. 1	10. 0	5, 020
5, 500	24. 43	620. 6	4. 1	9. 5	5, 520
6, 000	23. 98	609. 0	3. 1	9. 0	6, 040
6, 500	23. 53	597. 6	2. 1	8. 5	6, 550
7, 000	23. 09	586. 4	1. 1	8. 0	7, 070
7, 500	22. 65	575. 3	+0. 1	7. 5	7, 600
8, 000	22. 22	564. 4	−0. 8	7. 0	8, 110
8, 500	21. 80	553. 7	−1. 8	6. 5	8, 640
9, 000	21. 38	543. 2	−2. 8	6. 0	9, 160
9, 500	20. 98	532. 8	−3. 8	5. 5	9, 690
10, 000	20. 58	522. 6	−4. 8	5. 0	10, 220
10, 500	20. 18	512. 5	−5. 8	4. 5	10, 750
11, 000	19. 79	502. 6	−6. 8	4. 0	11, 280
11, 500	19. 40	492. 8	−7. 8	3. 5	11, 820
12, 000	19. 03	483. 3	−8. 8	2. 9	12, 360
12, 500	18. 65	473. 8	−9. 8	2. 4	12, 890
13, 000	18. 29	464. 5	−10. 8	1. 9	13, 440
13. 500	17. 93	455. 4	−11. 7	1. 4	13, 980
14, 000	17. 57	446. 4	−12. 7	0. 9	14, 520
14, 500	17. 22	437. 5	−13. 7	+0. 4	15, 070
15, 000	16. 88	428. 8	−14. 7	−0. 1	15, 620
15, 500	16. 54	420. 2	−15. 7	−0. 6	16, 170
16, 000	16. 21	411. 8	−16. 7	−1. 2	16, 730
16, 500	15. 89	403. 5	−17. 7	−1. 7	17, 280
17, 000	15. 56	395. 3	−18. 7	−2. 2	17, 830
17, 500	15. 25	387. 3	−19. 7	−2. 7	18, 400
18, 000	14. 94	379. 4	−20. 7	−3. 2	18, 960
18, 500	14. 63	371. 7	−21. 7	−3. 7	19, 520
19, 000	14. 33	364. 0	−22. 6	−4. 3	20, 100
19, 500	14. 04	356. 5	−23. 6	−4. 8	20, 660

TABLE III—Continued

ALTITUDE-PRESSURE-TEMPERATURE TABLE—Continued

Altitude, feet	Pressure		Temperature, °C.	Mean temperature, °C.	Isothermal altitude (+10° C.), feet
	in. Hg.	mm Hg.			
20, 000	13. 75	349. 1	−24. 6	−5. 3	21, 240
20, 500	13. 46	341. 9	−25. 6	−5. 8	21, 800
21, 000	13. 18	334. 7	−26. 6	−6. 3	22, 380
21, 500	12. 90	327. 7	−27. 6	−6. 9	22, 960
22, 000	12. 63	320. 8	−28. 6	−7. 4	23, 550
22, 500	12. 36	314. 1	−29. 6	−7. 9	24, 120
23, 000	12. 10	307. 4	−30. 6	−8. 4	24, 710
23, 500	11. 84	300. 9	−31. 6	−9. 0	25, 300
24, 000	11. 59	294. 4	−32. 5	−9. 5	25, 890
24, 500	11, 34	288. 1	−33. 5	−10. 0	26, 480
25, 000	11. 10	281. 9	−34. 5	−10. 5	27, 080
25, 500	10. 86	275. 8	−35. 5	−11. 1	27, 680
26, 000	10. 62	269. 8	−36. 5	−11. 6	28, 280
26, 500	10. 39	263. 9	−37. 5	−12. 1	28, 880
27, 000	10. 16	258. 1	−38. 5	−12. 7	29, 490
27, 500	9. 94	252. 5	−39. 5	−13. 2	30, 090
28, 000	9. 72	246. 9	−40. 5	−13. 7	30, 700
28, 500	9. 50	241. 4	−41. 5	−14. 3	31, 310
29, 000	9. 29	236. 0	−42. 5	−14. 8	31, 930
29, 500	9. 08	230. 7	−43. 4	−15. 3	32, 550
30, 000	8. 88	225. 6	−44. 4	−15. 9	33, 160
30, 500	8. 68	220. 5	−45. 4	−16. 4	33, 790
31, 000	8. 48	215. 5	−46. 4	−16. 9	34, 420
31, 500	8. 29	210. 6	−47. 4	−17. 5	35, 040
32, 000	8. 10	205. 8	−48. 4	−18. 0	35, 680
32, 500	7. 91	201. 0	−49. 4	−18. 6	36, 320
33, 000	7. 73	196. 4	−50. 4	−19. 1	36, 950
33, 500	7. 55	191. 8	−51. 4	−19. 6	37, 590
34, 000	7. 38	187. 4	−52. 4	−20. 2	38, 220
34, 500	7. 20	183. 0	−53. 4	−20. 7	38, 870
35, 000	7. 04	178. 7	−54. 3	−21. 3	39, 520
35, 332	6. 93	175. 9	−55. 0	−21. 6	39, 960
35, 500	6. 87	174. 5	−55. 0	−21. 8	40, 160
36, 000	6. 71	170. 4	−55. 0	−22. 3	40, 820
36, 500	6. 55	166. 4	−55. 0	−22. 8	41, 470
37, 000	6. 39	162. 4	−55. 0	−23. 3	42, 130
37, 500	6. 24	158. 6	−55. 0	−23. 8	42, 780
38, 000	6. 10	154. 9	−55. 0	−24. 3	43, 440
38, 500	5. 95	151. 2	−55. 0	−24. 8	44, 090
39, 000	5. 81	147. 6	−55. 0	−25. 2	44, 750
39, 500	5. 68	144. 1	−55. 0	−25. 6	45, 410
40, 000	5. 54	140. 7	−55. 0	−26. 0	46, 060
40, 500	5. 41	137. 4	−55. 0	−26. 4	46, 710
41, 000	5. 28	134. 2	−55. 0	−26. 8	47, 350
41, 500	5. 16	131. 0	−55. 0	−27. 2	48, 010
42, 000	5. 04	127. 9	−55. 0	−27. 6	48, 670
42, 500	4. 92	124. 9	−55. 0	−28. 0	49, 320
43, 000	4. 80	122. 0	−55. 0	−28. 3	49, 960
43, 500	4. 69	119. 1	−55. 0	−28. 6	50, 610
44, 000	4. 58	116. 3	−55. 0	−29. 0	51, 260
44, 500	4. 47	113. 5	55. 0	−29. 3	51, 930
45, 000	4. 36	110. 8	−55. 0	−29. 6	52, 590
45, 500	4. 26	108. 2	−55. 0	−29. 9	53, 240
46, 000	4. 16	105. 7	−55. 0	−30. 2	53, 870
46, 500	4. 06	103. 2	−55. 0	−30. 5	54, 530
47. 000	3. 97	100. 7	−55. 0	−30. 8	55, 200
47, 500	3. 87	98. 4	−55. 0	−31. 1	55, 830
48, 000	3. 78	96. 1	−55. 0	−31. 4	56, 480
48, 500	3. 69	93. 8	−55. 0	−31. 7	57, 140
49, 000	3. 61	91. 6	−55. 0	−31. 9	57, 790
49, 500	3. 52	89. 4	−55. 0	−32. 2	58, 450
50, 000	3. 44	87. 3	−55. 0	−32. 4	59, 100

TABLE IV

TEMPERATURE CORRECTION TABLE

Mean temperature, ° C.	Standard altitude, in feet									
	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000
−35	-------	-------	-------	-------	-------	-------	-------	-------	2, 120	2, 219
−34	-------	-------	-------	-------	-------	-------	-------	-------	2, 053	2, 144
−33	-------	-------	-------	-------	-------	-------	-------	-------	1, 987	2, 069
−32	-------	-------	-------	-------	-------	-------	-------	-------	1, 920	1, 994
−31	-------	-------	-------	-------	-------	-------	-------	-------	1, 853	1, 920
−30	-------	-------	-------	1, 057	1, 258	1, 433	1, 579	1, 698	1, 786	1, 845
−29	-------	-------	-------	1, 029	1, 222	1, 389	1, 528	1, 639	1, 720	1, 770
−28	-------	-------	-------	1, 000	1, 186	1, 346	1, 477	1, 580	1, 653	1, 696
−27	-------	-------	-------	971	1, 150	1, 302	1, 426	1, 521	1, 586	1, 621
−26	-------	-------	-------	943	1, 114	1, 259	1, 375	1, 462	1, 520	1, 546
−25	266	507	724	914	1, 078	1, 215	1, 324	1, 403	1, 453	1, 472
−24	259	493	702	886	1, 042	1, 172	1, 273	1, 344	1, 386	1, 397
−23	252	479	681	857	1, 006	1, 128	1, 221	1, 286	1, 319	1, 322
−22	245	465	660	829	970	1, 085	1, 170	1, 227	1, 253	1, 247
−21	238	451	639	800	934	1, 041	1, 119	1, 168	1, 186	1, 173
−20	231	437	617	771	898	998	1, 068	1, 109	1, 119	1, 098
−19	224	423	596	743	862	954	1, 017	1, 050	1, 053	1, 023
−18	217	409	575	714	826	911	966	991	986	949
−17	210	395	553	686	790	867	915	932	919	874
−16	203	381	532	657	755	824	864	874	852	799
−15	196	367	511	629	719	780	813	815	786	725
−14	189	353	490	600	683	737	761	756	719	650
−13	182	338	468	571	647	693	710	697	652	575
−12	175	324	447	543	611	650	659	638	585	500
−11	168	310	426	514	575	606	608	579	519	426
−10	161	296	405	486	539	563	557	520	452	351
−9	154	282	383	457	503	519	506	462	385	276
−8	147	268	362	429	467	476	455	403	319	202
−7	140	254	341	400	431	432	404	344	252	127
−6	133	240	319	371	395	389	353	285	185	52
−5	126	226	298	343	359	345	301	226	118	22
−4	119	212	277	314	323	302	250	167	52	97
−3	112	197	256	286	287	258	199	108	15	172
−2	105	183	234	257	251	215	148	50	82	247
−1	98	169	213	229	215	171	97	9	148	321

Values above the zigzag line are to be subtracted; those below, to be added.

TABLE IV—Continued

TEMPERATURE CORRECTION TABLE—Continued

Mean temperature, ° C.	Standard altitude, in feet									
	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000
0	91	155	192	200	179	128	46	68	215	396
1	84	141	171	171	143	84	5	127	282	471
2	77	127	149	143	107	41	56	186	349	545
3	70	113	128	114	71	3	107	245	415	620
4	63	99	107	86	35	46	159	304	482	695
5	56	85	85	57	1	90	210	362	549	769
6	49	71	64	29	37	133	261	421	616	844
7	42	57	43	0	73	177	312	480	682	919
8	35	43	22	29	109	220	363	539	749	994
9	28	28	0	57	145	263	414	598	816	1, 068
10	21	14	21	86	181	307	465	657	882	1, 143
11	14	0	42	114	217	350	516	716	949	1, 218
12	7	14	64	143	253	394	568	774	1, 016	1, 292
13	0	28	85	171	289	437	619	833	1, 083	1, 367
14	7	42	106	200	325	481	670	892	1, 149	1, 442
15	14	58	127	229	361	524	721	951	--------	--------
16	21	70	149	257	397	568	772	1, 010	--------	--------
17	28	84	170	286	432	611	823	1, 069	--------	--------
18	35	98	191	314	468	655	874	1, 128	--------	--------
19	42	112	212	343	504	698	925	1, 186	--------	--------
20	49	126	234	371	540	742	--------	--------	--------	--------
21	56	141	255	400	576	785	--------	--------	--------	--------
22	63	155	276	429	612	829	--------	--------	--------	--------
23	70	169	298	457	648	872	--------	--------	--------	--------
24	77	183	319	486	684	916	--------	--------	--------	--------
25	84	197	340	--------	--------	--------	--------	--------	--------	--------
26	91	211	361	--------	--------	--------	--------	--------	--------	--------
27	98	225	383	--------	--------	--------	--------	--------	--------	--------
28	105	239	404	--------	--------	--------	--------	--------	--------	--------
29	112	253	425	--------	--------	--------	--------	--------	--------	--------
30	119	267	446	--------	--------	--------	--------	--------	--------	--------

Values above the zigzag line are to be subtracted; those below, to be added.

TABLE IV—Continued

TEMPERATURE CORRECTION TABLE—Continued

Mean temperature, °C.	Standard altitud in feet									
	22, 000	24, 000	26, 000	28, 000	30, 000	32, 000	34, 000	36, 000	38, 000	40, 000
−35	2, 287	2, 323	2, 327	2, 297	2, 233	2, 132	1, 994	1, 819	1, 635	1, 452
−34	2, 204	2, 232	2, 227	2, 189	2, 116	2, 006	1, 859	1, 675	1, 483	1, 290
−33	2, 121	2, 141	2, 128	2, 082	1, 999	1, 881	1, 725	1, 532	1, 330	1, 128
−32	2, 038	2, 050	2, 029	1, 974	1, 883	1, 755	1, 590	1, 388	1, 177	966
−31	1, 956	1, 959	1, 929	1, 866	1, 766	1, 630	1, 456	1, 244	1, 024	804
−30	1, 873	1, 868	1, 830	1, 758	1, 649	1, 504	1, 321	1, 101	872	642
−29	1, 790	1, 777	1, 730	1, 650	1, 533	1, 379	1, 187	957	719	480
−28	1, 707	1, 686	1, 631	1, 542	1, 416	1, 253	1, 052	814	566	318
−27	1, 624	1, 595	1, 531	1, 434	1, 299	1, 128	918	670	413	156
−26	1, 541	1, 504	1, 432	1, 326	1, 183	1, 002	783	526	260	6
−25	1, 459	1, 413	1, 332	1, 218	1, 066	877	649	383	108	168
−24	1, 376	1, 322	1, 233	1, 110	949	751	514	239	45	330
−23	1, 293	1, 230	1, 134	1, 002	833	626	380	96	198	492
−22	1, 210	1, 139	1, 034	894	716	500	245	48	351	654
−21	1, 127	1, 048	935	786	599	375	111	192	504	816
−20	1, 044	957	835	678	483	249	24	335	656	978
−19	962	866	736	570	366	124	158	479	809	1, 140
−18	879	775	636	462	249	2	292	623	962	1, 302
−17	796	684	537	354	133	127	427	766	1, 115	1, 463
−16	713	593	437	246	16	252	561	910	1, 268	1, 625
−15	630	502	338	138	101	378	696	1, 053	1, 420	1, 787
−14	548	411	239	30	217	503	830	1, 197	1, 573	1, 949
−13	465	320	139	78	334	629	965	1, 341	1, 726	2, 111
−12	382	229	40	186	451	754	1, 099	1, 484	1, 879	2, 273
−11	299	138	60	294	567	880	1, 234	1, 628	2, 031	2, 435
−10	216	46	159	402	684	1, 005	1, 368	1, 772	2, 184	2, 597
−9	133	45	259	510	801	1, 131	1, 503	1, 915	2, 337	2, 759
−8	51	136	358	618	917	1, 256	1, 637	2, 059	2, 490	2, 921
−7	32	227	458	726	1, 034	1, 382	1, 772	2, 202	2, 643	3, 083
−6	115	318	557	834	1, 151	1, 507	1, 906	2, 346	2, 795	3, 245
−5	198	409	656	942	1, 267	1, 633	2, 041	2, 490	---------	---------
−4	281	500	756	1, 050	1, 384	1, 758	2, 175	2, 633	---------	---------
−3	364	591	855	1, 158	1, 501	1, 884	2, 310	2, 777	---------	---------
−2	446	682	955	1, 266	1, 617	2, 009	2, 444	2, 921	---------	---------
−1	529	773	1, 054	1, 374	1, 734	2, 135	2, 579	3, 064	---------	---------
0	612	864	1, 154	1, 482	1, 851	2, 260	---------	---------	---------	---------
+1	695	955	1, 253	1, 590	1, 967	2, 386	---------	---------	---------	---------
2	778	1, 047	1, 353	1, 698	2, 084	2, 511	---------	---------	---------	---------
3	861	1, 138	1, 452	1, 806	2, 201	2, 637	---------	---------	---------	---------
4	943	1, 229	1, 551	1, 914	2, 317	2, 762	---------	---------	---------	---------
5	1, 026	1, 320	1, 651	2, 022	---------	---------	---------	---------	---------	---------
6	1, 109	1, 411	1, 750	2, 130	---------	---------	---------	---------	---------	---------
7	1, 192	1, 502	1, 850	2, 238	---------	---------	---------	---------	---------	---------
8	1, 275	1, 593	1, 949	2, 346	---------	---------	---------	---------	---------	---------
9	1, 358	1, 684	2, 049	2, 454	---------	---------	---------	---------	---------	---------
10	1, 440	1, 775	---------	---------	---------	---------	---------	---------	---------	---------
11	1, 523	1, 866	---------	---------	---------	---------	---------	---------	---------	---------
12	1, 606	1, 957	---------	---------	---------	---------	---------	---------	---------	---------
13	1, 689	2, 048	---------	---------	---------	---------	---------	---------	---------	---------
14	1, 772	2, 139	---------	---------	---------	---------	---------	---------	---------	---------

Values above the zigzag line are to be subtracted; those below to be added.

TABLE IV—Continued

TEMPERATURE CORRECTION TABLE—Continued

Mean temperature, °C.	Standard altitude, in feet					
	40,000	42,000	44,000	46,000	48,000	50,000
−40	2, 262	2, 124	1, 987	1, 849	1, 711	1, 574
−39	2, 100	1, 953	1, 806	1, 659	1, 513	1, 366
−38	1, 938	1, 782	1, 626	1, 470	1, 314	1, 158
−37	1, 776	1, 611	1, 446	1, 280	1, 115	950
−36	1, 614	1, 440	1, 265	1, 091	917	742
−35	1, 452	1, 269	1, 085	901	718	535
−34	1, 290	1, 097	905	712	519	327
−33	1, 128	926	724	522	321	119
−32	966	755	544	333	122	89
−31	804	584	364	143	77	297
−30	642	413	183	46	275	505
−29	480	242	3	236	474	712
−28	318	71	177	425	673	920
−27	156	101	357	615	871	1, 128
−26	6	272	538	804	1, 070	1, 336
−25	168	443	718	993	1, 269	1, 544
−24	330	614	898	1, 183	1, 467	1, 752
−23	492	785	1, 079	1, 372	1, 666	1, 959
−22	654	956	1, 259	1, 562	1, 865	2, 167
−21	816	1, 128	1, 439	1, 751	2, 063	2, 375
−20	978	1, 299	1, 620	1, 941	2, 262	2, 583
−19	1, 140	1, 470	1, 800	2, 130	2, 461	2, 791
−18	1, 302	1, 641	1, 980	2, 320	2, 659	2, 999
−17	1, 463	1, 812	2, 161	2, 509	2, 858	3, 206
−16	1, 625	1, 983	2, 341	2, 699	3, 057	3, 414
−15	1, 787	2, 154	2, 521	2, 888	3, 255	3, 622
−14	1, 949	2, 326	2, 702	3, 078	3, 454	3, 830
−13	2, 111	2, 497	2, 882	3, 267	3, 653	4, 038
−12	2, 273	2, 668	3, 062	3, 457	3, 851	4, 246
−11	2, 435	2, 839	3, 243	3, 646	4, 050	4, 453
−10	2, 597	3, 010	--------	--------	--------	--------
−9	2, 759	3, 181	--------	--------	--------	--------
−8	2, 921	3, 352	--------	--------	--------	--------
−7	3, 083	3, 524	--------	--------	--------	--------
−6	3, 245	3, 695	--------	--------	--------	--------
−5	3, 407	3, 866	--------	--------	--------	--------

Values above the zigzag line are to be substracted; those below, to be added.

REPORT No. 247

PRESSURE OF AIR ON COMING TO REST FROM VARIOUS SPEEDS

By A. F. ZAHM
Aerodynamical Laboratory, Bureau of Construction and Repair, United States Navy

REPORT No. 247

PRESSURE OF AIR ON COMING TO REST FROM VARIOUS SPEEDS

By A. F. Zahm

SUMMARY

The text gives theoretical formulas from which is computed a table for the pressure of air on coming to rest from various speeds, such as those of aircraft and propeller blades. Pressure graphs are given for speeds from 1 cm. sec. up to those of swift projectiles.

The present treatment, slightly modified, was prepared for the Bureau of Aeronautics, Navy Department, February 17, 1926, and by it was submitted for publication to the National Advisory Committee for Aeronautics.

PRESSURE-SPEED FORMULAS FOR MODERATE SPEEDS

A solid surface in uniform translation through a frictionless incompressible fluid, otherwise quiescent, can thereby receive at one point or more a maximum pressure increase $\rho_0 V_0^2/2$, where ρ_0 is the fluid density, V_0 the body's speed. One calls $\rho_0 V_0^2/2$ the "full impact" or "stop" pressure; and any point where it occurs a "stagnation point" or "stop point." Likewise if the body is fixed in a uniform stream, of speed V_0, the incompressible fluid comes to rest at a stop point with the pressure increase $\rho_0 V_0^2/2$. Here the whole stop pressure above vacuo is

$$p_1 = p_0 + \rho_0 V_0^2/2 \tag{1}$$

if p_0 is the pressure in the unchecked part of the stream. In every case here treated p_0 is assumed void of gravity effect.

When a gas for which $p/p_0 = (\rho/\rho_0)^\gamma$ comes to rest adiabatically the stop pressure is

$$p_2 = p_0 \left[1 + \frac{(\gamma - 1)\rho_0 V_0^2}{2\gamma p_0}\right]^{\frac{\gamma}{\gamma - 1}} \tag{2}$$

as shown in hydrodynamics, $\gamma = C_p/C_v$ being the ratio of the specific heat at constant pressure to that at constant volume. This formula is valid for engineering speeds below that of sound in the fluid; for higher and for extremely low speeds other formulas will be given presently.

Expanding (2) gives

$$p_2 = p_0 + \rho_0 V_0^2/2 + p_0\left(\frac{\rho_0 V_0^2}{8\gamma p_0^2} + \ - \ - \ -\right)$$

which exceeds (1) by the parenthetical factor. This excess is negligible at sufficiently low speeds; but not at the speed of a fast airplane or propeller blade, as presently will be shown by some examples.

To furnish the aeronautical engineer with ready numerical values of (1), (2) for air on coming to rest, Table I has been computed for the standard values specified below it.[1] Taking $\gamma = 1.40$, one first writes (1), (2) in the convenient working forms

$$p_1/p_0 = 1 + 0.60471\ V_0^2 \times 10^{-9}, \qquad p_2/p_0 = (1 + 1.7277\ V_0^2 \times 10^{-10})^{3.50}$$

For speeds below that of sound no material error ensues from taking $\gamma = 1.40$ instead of the slightly different values given in physics.

---

[1] A like table was computed for C. & R. Report No. 129, dated May 13, 1919, and one giving five speeds was published by Finzi and Soldati in 1903, in their pamphlet "Esperimenti Sulla Dinamica dei Fluidi."

The computations were made by various members of the aerodynamics staff in the Construction and Repair Aerodynamical Laboratory of the United States Navy, and checked by the aeronautics staff at the Bureau of Standards. The diagrams were made by Mr. F. A. Louden.

The importance of the pressure excess due to compression may be judged from the tenth column of the table. For speeds under 70 miles an hour the excess is less than $\frac{1}{6}$ per cent of the impact pressure computed for air without compression. At 100 miles an hour, it is 0.41 per cent; at 150 miles, 0.96 per cent; at 300 miles, 4 per cent; at 800 miles, 31 per cent. The last is about the speed of sound and of some propeller tips, while 300 miles is attained by fast airplanes in diving.

VALIDITY OF FORMULA

The validity of (2) is here assumed without proof; viz, the compression is assumed to occur without sensible heat transfer. At speeds above 150 miles an hour, for which the density increment is no longer negligible, the compression of the air filament from p_0 to p_2 may occur in very brief time. To illustrate, suppose air streaming at 200 feet a second across a rod 1 inch in diameter. From both theory and experiment one knows that the speed is sensibly unchecked at points 1 foot before the rod and 1 foot behind it. Hence a particle traversing this range must receive its maximum compression in about $\frac{1}{200}$ second. The dissipation of compression heat in this case may be assumed negligible, both because of suddenness and because the heating or cooling of any filament is paralleled by that of its immediate neighbors, thus lessening the temperature gradient.

It is commonly assumed also that for usual wind tunnel speeds the stop pressure on a large body equals that on a like small one in like conditions. In 1902 the writer found the impact pressure in the nozzle of a $\frac{1}{8}$-inch pitot the same as in a pipe 5 inches in diameter when both were pointed upstream in a 6-foot wind tunnel maintaining a steady 40-mile wind. (Reference 1.) In December, 1925, he found the impact pressure in a square-ended glass tube of $\frac{1}{8}$-inch bore, pointed into a 40-mile wind, equal to that in a like tested neatly pointed hypodermic tube 0.01 inch in diameter,[2] truly to $\frac{1}{5000}$ inch of water.

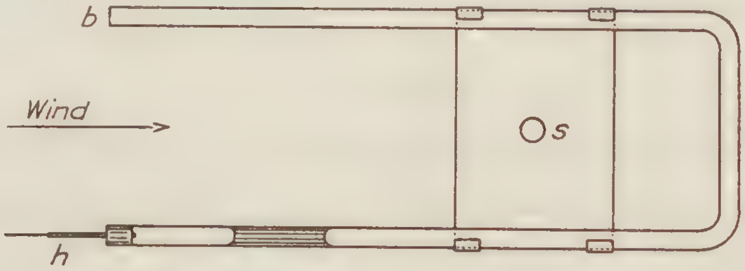


FIG. 1.—Glass U-tube pointing upwind and held by spindle s of aerodynamic balance. In a 40-mile wind, pressure in hypodermic nozzle h balances that at b truly to $\frac{1}{5000}$ inch of water. Bore of glass tube $\frac{1}{8}$ inch; bore of hypodermic tube 0.0097 inch

The arrangement for this latter test is shown in Figure 1. A glass U-tube of $\frac{1}{8}$-inch bore with arms in a horizontal plane and pointing upstream, is held by a sheet metal clamp mounted on the spindle of the aerodynamic balance in the 4-foot wind tunnel. With both ends wide open in a 40-mile wind the U-tube was adjusted, by canting the balance, first till the small piston of alcohol there shown just moved forward, then till it just moved backward. The amount of cant was indicated by an Ames dial gauge at the tip of the balance beam. Now, with the glass arms in their neutral position, and one plugged with a hypodermic needle of $\frac{1}{100}$-inch bore, as shown, the piston rested in the same equilibrium position as before in the same wind. Since the dial gauge showed that a cant of 1 in 10,000 is sufficient to move a piston 3 inches long, of alcohol of specific gravity 0.81, the differential pressure between the fine and coarse nozzle can not exceed about $\frac{1}{5000}$ inch of water.

For the medium speeds listed in Table I many experiments have shown that the pitot impact pressure equals the reservoir pressure; that is, the pressure of stagnant air from which the stream would issue with the speed V_0 through a perfect nozzle. For such speeds therefore no corroborative data need be presented. For swifter flows Dr. Briggs furnishes some unpublished measurements made by himself and Dr. Buckingham showing that the static air pressure in a reservoir equals the pitot pressure in its fair discharge nozzle at exit speeds of 400 to 1,000 feet a second, but progressively exceeds it for higher speeds up to that of sound, though the exess is but a few per cent. Check measurements with improved apparatus will be made by them before publication.

---

[2] Inside diameter 0.0097; outside, 0.0111 inch.

LOW-SPEED FORMULA

Table I therefore is valid for bodies of all but microscopic size. For small bodies at low speeds a viscous pressure may have to be added to the inertia pressure. As shown in hydrodynamics, the nose impact pressure on a sphere of radius a, fixed in a boundless uniform stream of liquid, of viscosity μ, is

$$p_3 = \frac{1}{2}\rho_o V_o^2 + \frac{3}{2}\frac{\mu V_o}{a} \tag{3}$$

The ratio of this to $\rho_o V_o^2/2$, found for an inviscid liquid is

$$y = p_3/.5\,\rho_o V_o^2 = 1 + \frac{3}{R} \tag{4}$$

where $R = aV_o/\nu$ is Reynolds Number. On plain section paper y plots against R as an hyperbola asymptotic to the lines $y=1$, $R=o$.

For R quite large, as assumed for Table I, the viscous term is inappreciable; for R small, as when a mist particle falls in air, that term is predominant.

Assuming p_3 to express the impact pressure of a fine pitot at small speeds, Muriel Barker (Reference 2), of Cambridge University, plotted it against the impact pressure p_e determined by her for the point of a pitot 1 millimeter in diameter held at the center of a long brass pipe 11 millimeters in diameter[3] conducting water in steady stream-line flow at approximately 15° C. Fixed speeds of unchecked flow from 0.82 to 11.76 centimeter-seconds at the pipe's center were used. For $V_o < 6$ centimeter-seconds, or for $R < 30$, faired values of p_e plot as a straight line

$$p_e = p_3/1.1; \tag{5}$$

for $R > 30$, $p_e = .5\ \rho_o V_o^2$.

No correction of p_e was made for the ratio of the diameters of the pipe and pitot. Until this has been done (5) may be regarded as but an approximate expression for the differential pressure of said pitot in a boundless stream.

HIGH-SPEED FORMULA

For speeds well above that of sound the value of (2) is doubtful; first because γ is then quite variable, secondly, because the pressures given by (2) are much higher than the nose pressures found in high-speed projectiles. For such speeds Rayleigh (Reference 3) derives a special formula which, with $\gamma = 1.40$ reduces to

$$\frac{p_2}{p_o} = \frac{166.7\ V_o^7}{C^2(7V_o^2 - C^2)^{2.5}} \tag{6}$$

where C is the speed of sound in the unchecked stream. For $V_o = C$, (6) and (2) give the same value of p_2/p_o. Rayleigh's formula is indorsed in Reference 4.

PRESSURE-SPEED GRAPHS

Fig. 2 shows graphically the absolute pressures given in Columns 4, 5 of Table I; also the impact pressures got from them by subtracting unity.

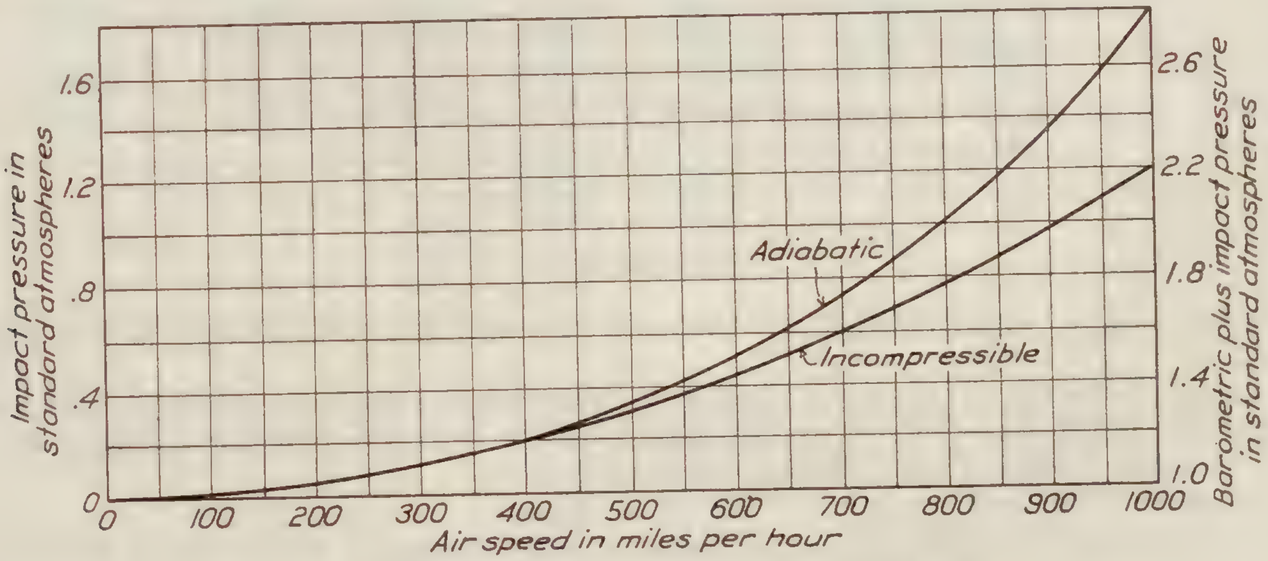


FIG. 2.—Pressure of air on coming to rest from various speeds

---

[3] The inner and outer diameters of the pipe and pitot can not be gleaned from the paper cited.

With p = impact pressure plus viscous pressure, the upper curve of Fig. 3 delineates $p/.5\rho_o V_o^2$ versus V_o for air on coming to rest against the nose of a sphere 1 millimeter in diameter. It shows the effect of viscosity at low speed and adiabatic compression at high speed. The lower curve gives $p/.5\rho_o V_o^2$ for water, in comparison with Miss Barker's readings with the one millimeter pitot. Semilog paper is used to lengthen the low-speed scale.

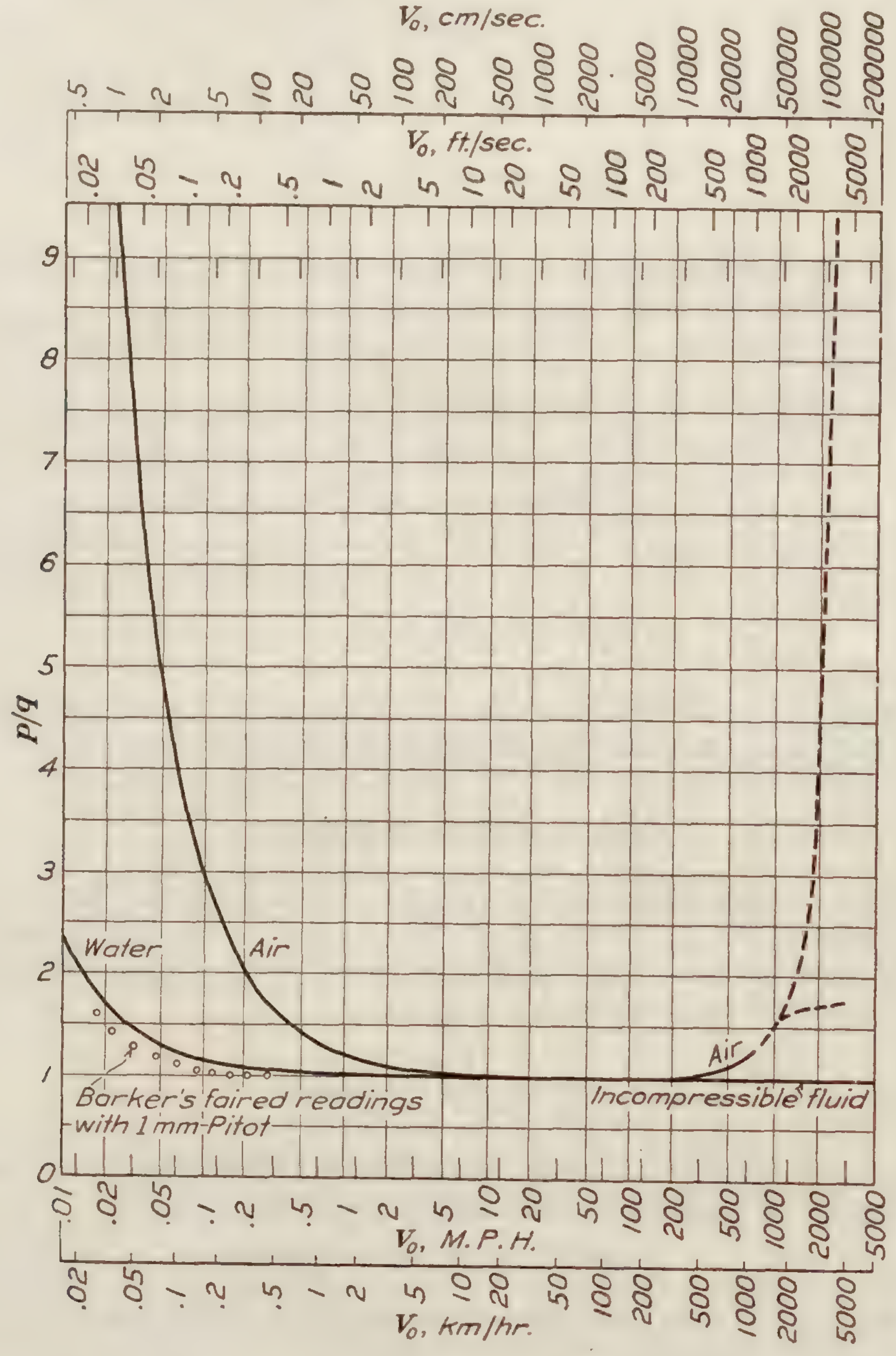


FIG. 3.—Pressure of fluid on coming to rest from various speeds. p/q vs. V_o; p=impact pressure plus viscous pressure, sphere 1 millimeter diameter; $q=\rho_o V_o^2/2$

For ultra sound speeds two graphs are given in Figure 3; the higher derived from (2), the lower from (6). The true impact pressure at these speeds is found by Stanton to be given by Rayleigh's formula within ½% at 2.3 times the speed of sound (Reference 4).

REFERENCES

1. A. F. Zahm, "Measurement of air velocity and pressure," Phys. Review, December, 1903.

2. BARKER, MURIEL, "On the use of very small pitot-tubes for measuring wind velocity," Proc. Roy. Soc. Lon., Series A, Vol. Cl, 1922. (This reference was furnished the writer by Dr. H. L. Dryden, United States Bureau of Standards.)

3. RAYLEIGH, "Scientific papers," Vol. V, p. 608.

4 T. E. Stanton, "On the Flow of Gases at High Speeds," Proc. Royal Soc. IIIA, 1926, No. A758.

TABLE I

PRESSURE OF AIR ON COMING TO REST FROM VARIOUS SPEEDS

(Symbols defined below)

Air speed			Barometric plus impact pressure in standard atmospheres. 1 std. atmo. = 1.0133×10^6 dynes/cm^2 = p_o		Impact pressure in pounds per square foot 1 std. atmo. = 2116.8 lb. per sq. ft.		Impact pressure in inches of water 1 std. atmo. = 407.2 in. of water		Percentage difference
Miles per hour	Knots per hour	Kilometers per hour	Incompressible $p_1/p_o = 1+.60471\times 10^{-9} V_o^2$	Adiabatic $p_2/p_o = (1+1.7277\times10^{-10} V_o^2)^{3.50}$	Incompressible	Adiabatic	Incompressible	Adiabatic	
0	0	0	1.00000	1.00000	0.000	0.000	0.000	0.000	0.00
10	8.7	16.1	1.00012	1.00012	.254	.254	.049	.049	.00
20	17.4	32.2	1.00048	1.00048	1.016	1.016	.196	.196	.00
30	26.1	48.3	1.00109	1.00109	2.307	2.307	.444	.444	.00
40	34.7	64.4	1.00193	1.00193	4.085	4.085	.786	.786	.00
50	43.4	80.5	1.00302	1.00302	6.393	6.393	1.230	1.230	.00
60	52.1	96.5	1.00435	1.00436	9.208	9.229	1.771	1.774	.17
70	60.8	112.6	1.00592	1.00593	12.532	12.553	2.411	2.415	.17
80	69.5	128.7	1.00773	1.00775	16.363	16.405	3.148	3.156	.26
90	78.2	144.8	1.00979	1.00982	20.724	20.787	3.987	3.999	.31
100	86.8	160.9	1.01208	1.01213	25.571	25.677	4.919	4.939	.41
110	95.5	177.0	1.01462	1.01470	30.948	31.117	5.953	5.986	.55
120	104.2	193.1	1.01740	1.01751	36.832	37.065	7.085	7.130	.63
130	112.9	209.2	1.02042	1.02057	43.225	43.543	8.315	8.376	.73
140	121.6	225.3	1.02368	1.02389	50.126	50.570	9.643	9.728	.89
150	130.3	241.4	1.02719	1.02745	57.556	58.106	11.072	11.178	.96
160	138.9	257.4	1.03094	1.03128	65.494	66.214	12.599	12.737	1.10
170	147.6	273.5	1.03492	1.03536	73.919	74.840	14.219	14.399	1.26
180	156.3	289.6	1.03915	1.03970	82.873	84.037	15.942	16.166	1.41
190	165.0	305.7	1.04362	1.04430	92.335	93.774	17.762	18.039	1.56
200	173.7	321.8	1.04834	1.04918	102.326	104.104	19.684	20.026	1.74
210	182.4	337.9	1.05329	1.05431	112.804	114.963	21.700	22.115	1.91
220	191.0	354.0	1.05849	1.05972	123.812	126.415	23.817	24.318	2.10
230	199.7	370.1	1.06392	1.06540	135.306	138.439	26.028	26.631	2.32
240	208.4	386.2	1.06960	1.07135	147.329	151.034	28.341	29.054	2.52
250	217.1	402.3	1.07553	1.07758	159.882	164.221	30.756	31.591	2.72
260	225.8	418.3	1.08169	1.08410	172.921	178.023	33.264	34.246	2.95
270	234.5	434.4	1.08809	1.09090	186.469	192.417	35.870	37.015	3.19
280	243.2	450.5	1.09474	1.09799	200.546	207.425	38.578	39.902	3.43
290	251.8	466.6	1.10163	1.10537	215.130	223.047	41.384	42.907	3.68
300	260.5	482.7	1.10876	1.11305	230.223	239.304	44.287	46.034	3.95
310	269.2	498.8	1.11613	1.12102	245.824	256.175	47.288	49.279	4.21
320	277.9	514.9	1.12374	1.12931	261.933	273.723	50.387	52.655	4.50
330	286.6	531.0	1.13160	1.13790	278.571	291.907	53.588	57.532	4.78
340	295.3	547.1	1,13969	1.14680	295.696	310.746	56.882	59.777	5,09
350	303.9	563.2	1.14803	1.15602	313.350	330.263	60.278	63.531	5.39
400	347.4	643.6	1.19335	1.20707	409.283	438.326	78.732	84.319	7.11
500	434.2	804.5	1.30210	1.33612	639.485	711.499	123.015	136.868	11.26
600	521.0	965.4	1.43503	1.50688	920.872	1,072.964	177.144	206.402	16.51
700	607.9	1,126.3	1.59212	1.72815	1,253.400	1,541.348	241.111	296.503	22.97
800	694.7	1,287.2	1.77338	2,01124	1.637.091	2,040.593	314.920	411.777	30.75
900	781.6	1,448.1	1.97881	2.35142	2,071.945	2,860.686	398.571	550.298	38.08
1,000	868.4	1,609.0	2.20841	2.82371	2,557.962	3,860.429	492.065	742.615	50.92
11.5	10	18.5	1.00016	1.00016	.339	.339	.065	.065	.00
23.0	20	37.1	1.00064	1.00064	1.355	1.355	.261	.261	.00
34.5	30	55.6	1.00144	1.00144	3.048	3.048	.586	.586	.00
46.1	40	74.1	1.00256	1.00256	5.419	5.419	1.042	1.042	.00
57.6	50	92.7	1.00401	1.00401	8.488	8.488	1.633	1.633	.00
69.1	60	111.2	1.00577	1.00578	12.214	12.235	2.350	2.354	.17
80.6	70	129.7	1.00785	1.00787	16.617	16.659	3.197	3.205	.25
92.1	80	148.3	1.01026	1.01029	21.718	21.782	4.178	4.190	.29
103.6	90	166.8	1.01298	1.01304	27.476	27.603	5.285	5.310	.47
115.2	100	185.3	1.01603	1.01612	33.932	34.123	6.527	6.564	.57
126.7	110	203.9	1.01939	1.01952	41.045	41.320	7.896	7.949	.67
138.2	120	222.4	1.02308	1.02327	48.856	49.258	9.398	9.476	.83
149.7	130	240.9	1.02708	1.02735	57.323	57.894	11.027	11.137	1.00
161.2	140	259.5	1.03141	1.03177	66.489	72.251	12.790	12.937	1.12
172.7	150	278.0	1.03606	1.03652	76.332	77.306	14.684	14.871	1.27
184.2	160	296.5	1.04103	1.04163	86.852	88.122	16.707	16.952	1.47
195.8	170	315.1	1.04632	1.04709	98.050	99.680	18.862	19.175	1.66
207.3	180	333.6	1.05192	1.05289	109.904	111.958	21.142	21.537	1.87
218.8	190	352.1	1.05785	1.05906	122.457	125.018	23.557	24.049	2.09
230.3	200	370.7	1.06410	1.06558	135.687	138.820	26.102	26.704	2.31

$p_o = 1.0133\times10^6$ dynes/cm^2 = 1 std. atmo$\left.\right\}$ U. S. Std. values. (See N. A. C. A. Technical Report No. 218.)
$\rho_o = .0012255$ gm/cm^3 ------------------$\left.\right\}$
$\gamma = 1.40$.
V_0 = Air speed in cm/sec.
p_1/p_o (incompress.) $= 1+\rho_o V_o^2/2 p_o = 1+.60471\times10^{-9} V_o^2$ atmo.
p_2/p_o (adiabatic) $= (1+(\gamma-1) \rho_o V_o^2/2 \gamma p_o)^{\gamma/\gamma-1} = (1+1.7277\times10^{-10} V_o^2)^{3.50}$ atmo.
Using $\gamma = 1.401$ would lower the values in columns 7 and 9 less than 0.02 % for speeds less than 350 miles per hour.

REPORT No. 248

THE CORROSION OF MAGNESIUM AND OF THE MAGNESIUM ALUMINUM ALLOYS CONTAINING MANGANESE

By J. A. BOYER
American Magnesium Corporation

REPORT No. 248

THE CORROSION OF MAGNESIUM AND OF THE MAGNESIUM ALUMINUM ALLOYS CONTAINING MANGANESE

By J. A. Boyer[1]

SUMMARY

The extensive use of magnesium and its alloys in aircraft has been seriously handicapped by the uncertainties surrounding their resistance to corrosion. This problem has been given intense study by the American Magnesium Corporation and at the request of the Subcommittee on Materials for Aircraft of the National Advisory Commitee for Aeronautics, Mr. J. A. Boyer, of the American Magnesium Corporation, has prepared the following report on the corrosion of magnesium.

INTRODUCTION

Although considerable progress has been made in the development of strong magnesium alloys, the corrosion of these alloys has received very little study. For that reason the corrodibility of the metal itself has been the subject of considerable misunderstanding. Magnesium of inferior quality has often been placed on the market; this metal usually contained chloride and corroded badly when subject to even ordinary atmospheric conditions. Alloys have been prepared more or less indiscriminately from the standpoint of physical properties alone, and their rapid corrosion has been attributed to the tendency of magnesium itself to corrode rather than to the nature and proportion of the alloying ingredients.

Contrary to popular belief, pure magnesium is quite resistant to corrosion. However, the physical properties of the pure metal make it unfit for most structural purposes, and the alloys having desirable physical properties are usually not resistant to corrosion. The present investigation deals with the development of a resistant magnesium alloy by a variation in composition.

The natural alloying element for magnesium is aluminum. The latter, like magnesium, has a very low density and the addition required does not cause any appreciable increase in the density of the alloy over that of the pure metal. Aluminum is soluble in solid magnesium up to at least 10 per cent at the eutectic temperature, and the alloys may be subject to heat treatment and artificial aging. An exhaustive survey of the alloy field has not shown any alloying ingredient as satisfactory from the physical standpoint as aluminum, and for that reason the study of corrosion has been chiefly confined to the magnesium-aluminum series. The corrosion resistance of these alloys has been increased approximately 50 times without any sacrifice in physical properties.

Preliminary corrosion tests showed that the addition of small amounts of manganese greatly increased the resistance to corrosion of the magnesium alloys containing aluminum. It was known that the higher aluminum alloys corroded rapidly, supposedly owing to the presence of undissolved aluminum constituent. The results with the addition of manganese were very hard to duplicate, and occasionally two alloys of practically the same analysis would show very different corrosive properties. A study was undertaken to investigate the function of manganese in preventing corrosion, and to determine if possible the reason for the frequently anomalous results. The work was carried out along two different lines: Microscopic and metallographic examination, and potential measurements.

---

[1] Chief chemist, American Magnesium Corporation.

GENERAL NATURE OF CORROSIVE ACTION

It is generally accepted that the corrosion of metals in salt solutions is due to a displacement of hydrogen from the water. The less reactive metals do not have a high enough solution potential to displace hydrogen as a gas on the surface of the metal and the film of hydrogen formed must be removed by oxidation with atmospheric oxygen before further solution can take place. For this reason the corrosion of iron and steel in neutral solutions depends almost entirely on the amount of atmospheric oxygen which reaches the metal surface per unit time. If oxygen is excluded, corrosion practically ceases. In the case of magnesium, however, the solution potential is sufficiently high to displace hydrogen as a gas, so that corrosion takes place continuously and is practically independent of oxygen diffusion. As the latter is a comparatively slow process, the rate of corrosion in salt solutions increases enormously when the diffusion of oxygen ceases to be the controlling factor, and rapid corrosion continues until stopped by the formation of a film of corrosion product.

The corrosion of magnesium by immersion in salt solutions is a much more accelerated test than is the case with any other metal, owing to this direct displacement of hydrogen. Thus an alloy containing 4 per cent aluminum, while as resistant as iron when subjected to atmospheric corrosion or weathering, will be completely disintegrated by salt water in four or five days unless some alloying ingredient is added to inhibit corrosion. In comparison, an alloy which remains intact when immersed in salt water for a period of one or two weeks would be considered quite resistant. Specimens of such an alloy have been subjected to very severe atmospheric conditions, including exposure to both rain and acid fumes for a period of a year, and the results are comparable to that shown by the aluminum-base alloys in common use.

COMPARATIVE CORROSION RATE OF PURE METAL AND THE MAGNESIUM-ALUMINUM ALLOYS

Corrosion tests of more than 50 specimens of magnesium ingot taken at random from stock have shown that pure magnesium is quite resistant to corrosion. Machined specimens immersed in salt solutions of various concentrations for a period of two months remained intact and usually showed very little pitting. Four pieces of magnesium after two months' immersion in salt solution are shown in Figure 1. The specimens were acid cleaned after removal from the corroding medium.

With the addition of aluminum to magnesium the rate of corrosion increases enormously. A 4 per cent alloy of even half-inch thickness will be completely disintegrated in less than a week; the 8 per cent alloy corrodes even more rapidly. The effect of aluminum on corrosion is shown in Figure 2, which represents the result of a 48-hour intermittent immersion test, using 2 per cent sodium chloride solution.

The test pieces were 3 x 1⅛ inches x $\frac{3}{16}$ inch and weighed approximately 20 grams. They were not cleaned except to be rubbed down with a dry cloth, and the surface was that of ordinary extruded metal.

The loss in weight of each specimen after completion of the test is given in the following table:

Alloy	Loss in weight
Per cent Al	*Grams*
2	2.8
3	6.7
4	10.9
5	9.7
6	11.2
8	16.3

As this loss in weight occurred in only 48 hours, the accelerated nature of the intermittent immersion test is evident.

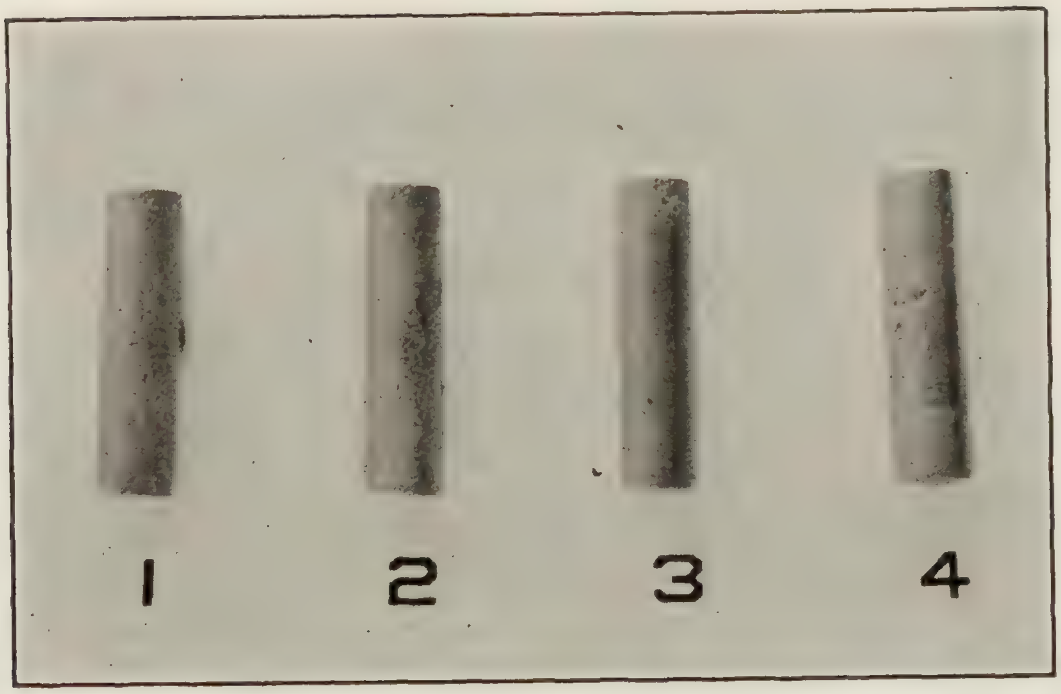


FIG. 1.—Machined pieces of magnesium after two months' immersion in salt solution. Specimens 1 and 2 immersed in 2 per cent NaCl solution. Specimens 3 and 4 immersed in 10 per cent NaCl solution

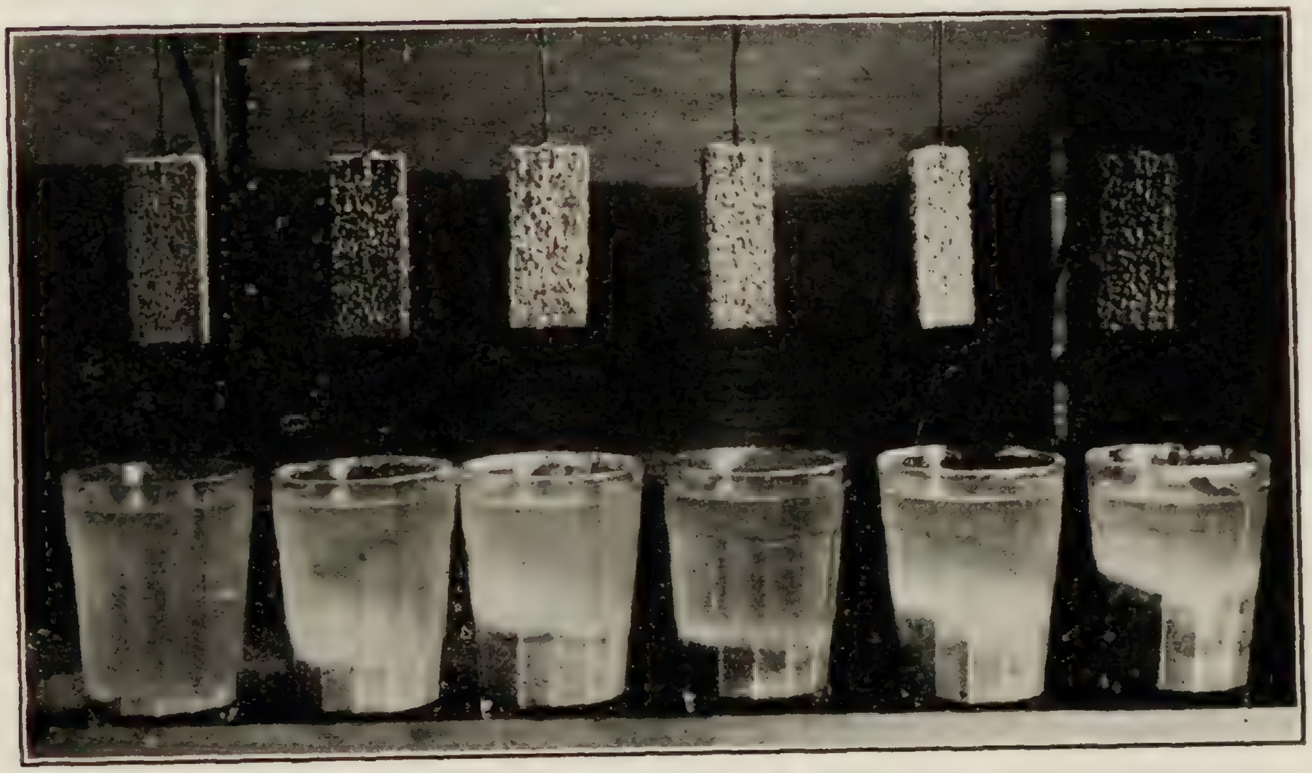


FIG. 2.—From left to right, 2, 3, 4, 5, 6, and 8 per cent aluminum, intermittent immersion, 2 per cent NaCl solution, 48 hours

INHIBITING EFFECT OF SMALL AMOUNTS OF MANGANESE

Quantitative data were next obtained on the effect of manganese in preventing the corrosion of the aluminum alloys. Seven alloys were specially prepared using different qualities of raw material. The composition of the alloys is given below:

COMPOSITION OF CORROSION ALLOYS

Alloy	Composition		Raw materials and preparation
No.	*Al*	*Mn*	
1	4.46		99.98 per cent aluminum, 99.99 per cent Mg, melted under argon.
2	4.39		Same as No. 1.
3	4.11		Commercial aluminum, 99.85 per cent Mg, air cast (chill).
4	4.61	0.29	99.98 per cent aluminum, 99.99 per cent Mg, specially pure Mn-Mg alloy, melted under argon.
5	4.48	.29	Commercial manganese-aluminum alloy, 99.99 per cent Mg, melted under argon.
6	4.23	.27	Same as No. 4.
7	3.82	.22	Commercial manganese-aluminum alloy, 99.99 per cent Mg, air cast (chill).

The test specimens were of the same dimensions as in the previous test, 3 x 1⅛ inches x $\frac{3}{16}$ inch. They were cleaned by rubbing down with a dry cloth and subjected to the 48-hour intermittent immersion test, using 2 per cent sodium chloride solution. Duplicate tests were run; the specimens were scoured with a stiff brush after removal from the corroding medium, and were cleaned by dipping in 10 per cent nitric acid for 20 seconds. There was some unavoidable loss in weight due to acid cleaning, but the loss was small and the results are more accurate than if the specimens had been weighed before cleaning. The loss in weight of the corroded specimens is given in the following table. As the test pieces were all of the same size, the loss was not reduced to grams per unit area.

LOSS IN WEIGHT OF CORRODED SPECIMENS

Alloy	Approximate composition	Loss in weight	
No.		*Test No. 1*	*Test No. 2*
1	4 per cent Al	8	7.5
2	4 per cent Al	10.9	10.1
3	4 per cent Al	6.4	5.4
4	4 per cent Al 0.3 per cent Mn	.3	.4
5	4 per cent Al 0.3 per cent Mn	.4	.4
6	4 per cent Al 0.3 per cent Mn	.5	.5
7	4 per cent Al 0.3 per cent Mn (air cast)	5.4	3.9

It will be observed that the loss in weight of the aluminum alloys containing no manganese is from 20 to 30 times as great as with specimens 4, 5, and 6, which contain approximately three-tenths per cent manganese. The abnormal loss of the air cast specimen presented a problem for further investigation.

A more striking illustration of the effect of manganese on the corrosion of the magnesium-aluminum alloys is shown in specimens 8 and 9 of Figure 4. The former is a 4 per cent aluminum alloy containing three-tenths per cent manganese, which has been immersed in a 10 per cent salt solution for four days. The specimen is scarcely pitted. Specimen No. 9 of the same composition except for the manganese, and immersed in the same strength salt solution for the same length of time, is almost completely disintegrated.

METALLOGRAPHIC STUDY OF CORROSION

The rapid corrosion of magnesium alloys in comparison with pure metal is usually explained by the assumption that the undissolved constituents in the alloy act as cathodic elements of a galvanic couple, and corrosion is caused by the difference in potential thus established. If the magnesium-aluminum alloys corrode rapidly, owing to the introduction of undissolved constituents, and if manganese almost completely counteracts this accelerated corrosion, it would be reasonable to assume that manganese might bring about some change in the microstructure of the alloy. It is generally believed that pitting of the more reactive metals is associated with the presence or segregation of some impurity, although this is not the case in the oxygen diffusion

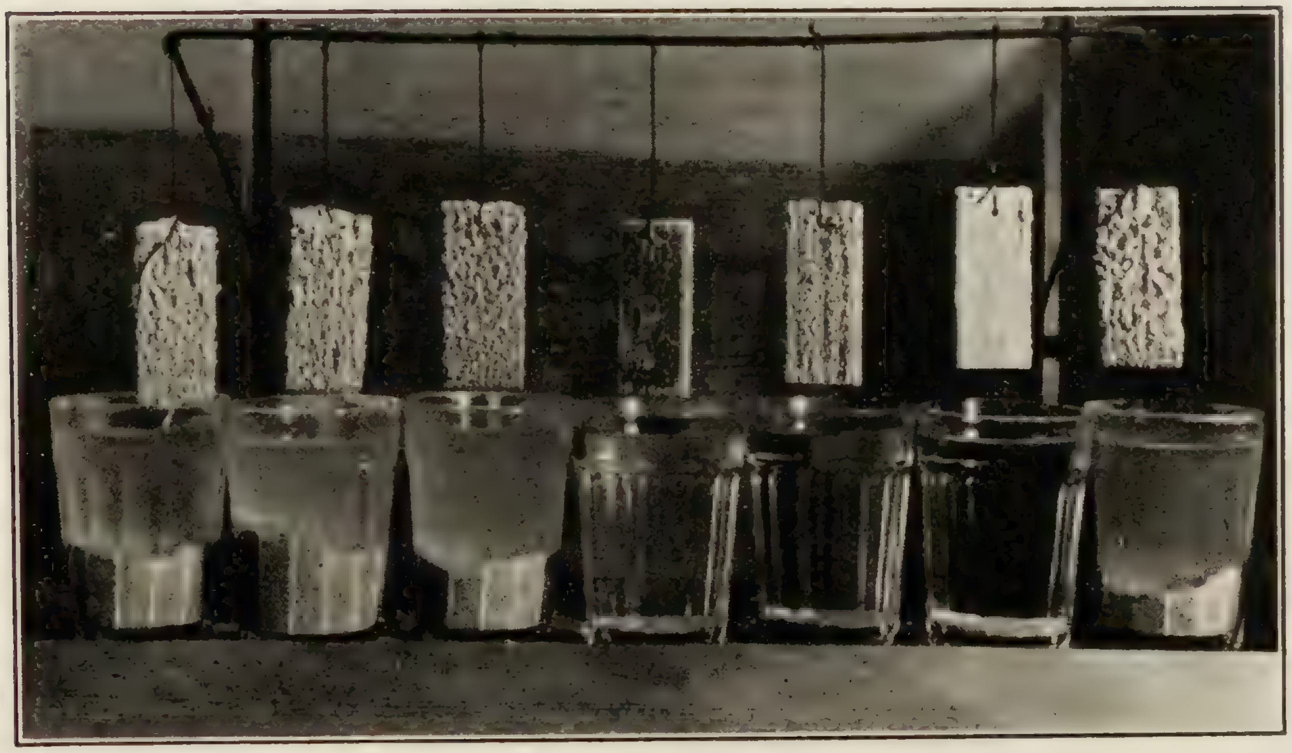


FIG. 3.—Specimens from left to right are numbers 1 to 7 of preceding table

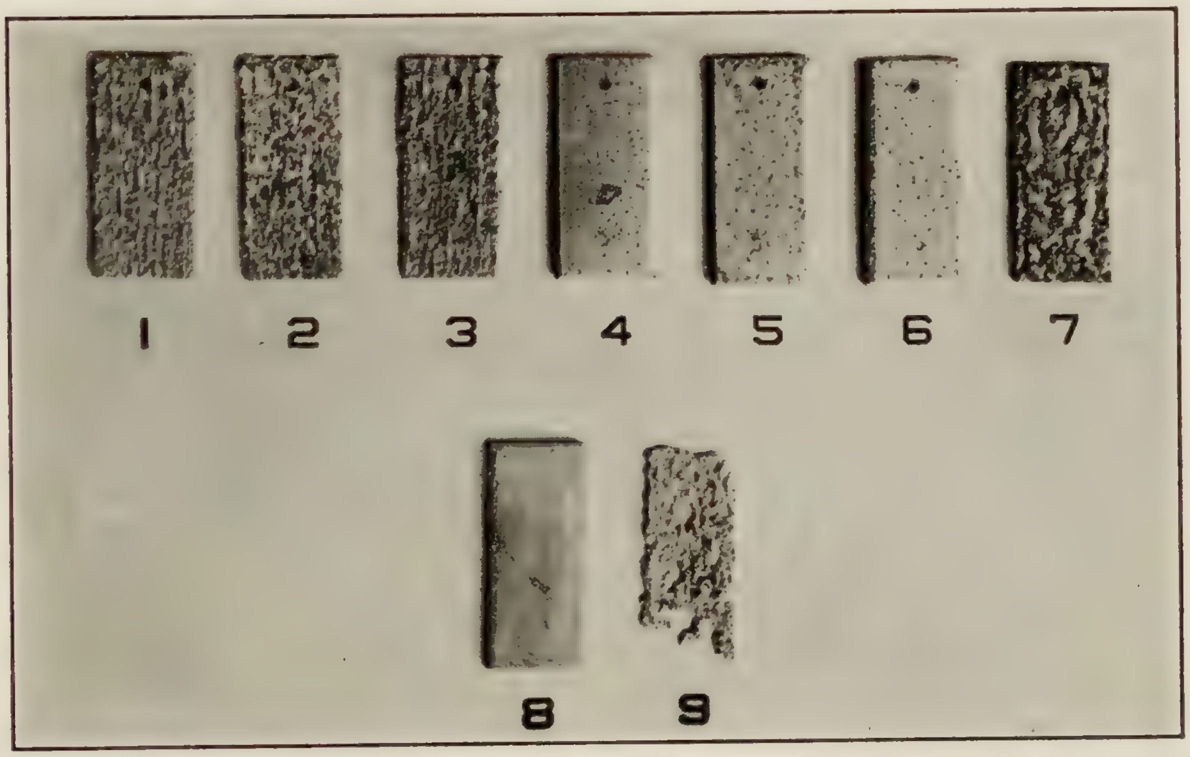


FIG. 4.—Specimens 1–7, same test as in Figure 3. Specimen 8, 4 per cent Al, 3 per cent Mn, and 9, 4 per cent Al in 10 per cent salt solution four days

type of corrosion. A metallographic examination was made of a large number of corroded specimens, with the twofold purpose of establishing a relation between the corrodibility of the alloy and the constituents present, and also to determine the relation, if any, between pitting and the segregation of impurities. The results showed that the rate of corrosion was practically independent of the microstructure of the alloy as revealed by ordinary methods of polishing and etching.

Figure 5 shows the microstructure of an alloy which was comparatively resistant to corrosion. A considerable quantity of magnesium silicide was present and also a large number of small hard particles not definitely identified. These hard particles are usually present in the aluminum alloys and are believed to be due to iron.

Figure 6 shows the structure of an alloy which corroded rapidly and was completely disintegrated by salt water. It is more nearly homogeneous than the resistant alloy shown in Figure 5. The same hard particles are present but no appreciable amount of silicide was observed.

Silicide was not responsible for the inhibitive effect, as alloys having a microstructure almost identical with Figure 6 were also quite resistant.

These examples are typical of all the specimens examined. No segregation of impurities was observed either in or near the pits, and no cause of either general or localized corrosion was evident.

EXAMINATION OF POLISHED SPECIMENS DURING THE PROCESS OF CORROSION

As the corrosion of magnesium in the initial stage is very rapid, it is possible with the aid of the microscope to observe the actual progress of the corrosive attack while the specimen is immersed in salt water.

The microscope used for these experiments was the ordinary biological microscope, fitted with a vertical illuminator and a 16-mm. objective. The latter was kept just above the surface of the liquid. Much better resolution and brilliancy were obtained with a low-power objective than with a higher power objective immersed in the solution.

The first alloys examined were those containing aluminum but no manganese; examination was then made of the alloys containing both manganese and aluminum. The alloys containing from 3 to 4 per cent aluminum usually consist of a homogeneous solid solution. When a polished specimen of such an alloy is immersed in salt water the surface becomes tarnished almost immediately. Under the microscope this tarnish is light brown, and the usual appearance is shown in Figure 7. It will be noted that the tarnish does not completely cover the entire surface of the metal, but there is a network of light areas which are practically unaffected. That the pattern produced is due to an attack which dissolves the metal surface is shown by the fact that scratches and other imperfections which are smoothed over on final polishing are quickly revealed by the action of salt water. It appears that the slightly flowed surface due to the final polish is eaten off.

A casual observation of the tarnish pattern might not indicate any relation between tarnish and the structure of the metal. However, when alloys solidified under conditions favorable to the growth of dendrites were polished and immersed in salt water, it was found that the tarnish pattern was almost entirely dendritic. The brown areas corresponded to the primary magnesium-rich cores or dendrites, and the lighter areas were presumably richer in aluminum. In practically every case where a particle of undissolved aluminum constituent was observed, it was located in the lighter areas.

Hydrogen was liberated simultaneously with the development of the tarnish pattern. The first bubbles were quite large and were scattered irregularly over the surface; on removal by shaking they did not tend to form again in the same place. However, there were very small points scattered over the alloy from which a very fine stream of hydrogen bubbles came continuously. These points apparently acted as cathodes, as the magnesium immediately surrounding the point from which gas was evolved was unattacked. It was difficult to determine the nature of these cathode areas or particles, both because of the stream of bubbles coming

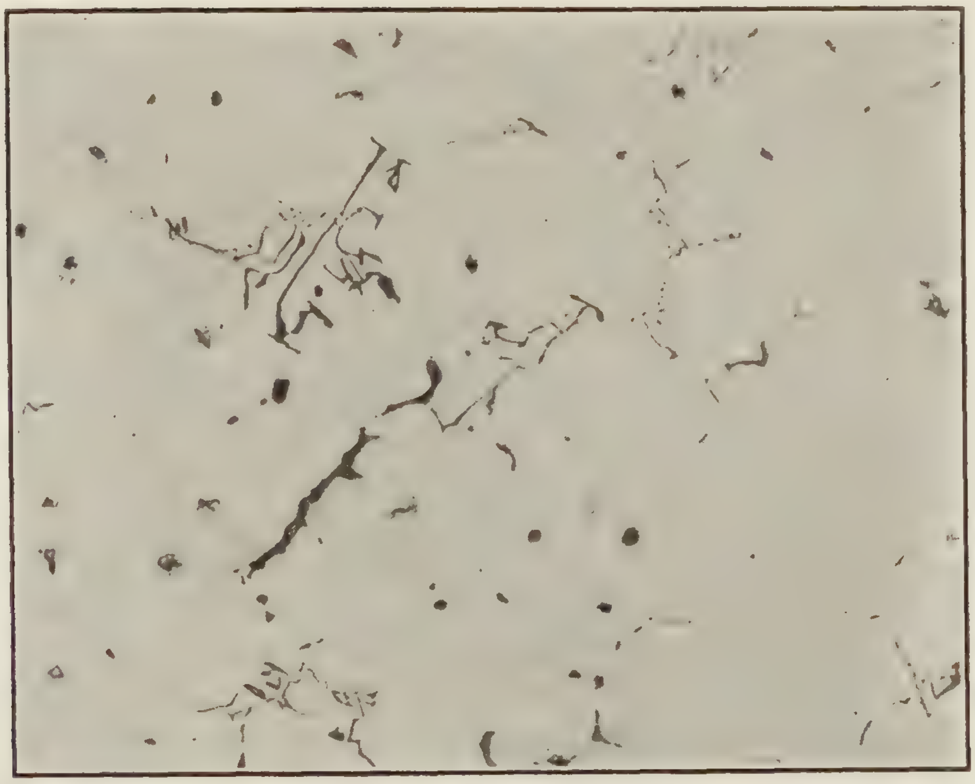


FIG. 5.—Mag. 100 ×. Microstructure of an alloy fairly resistant to corrosion

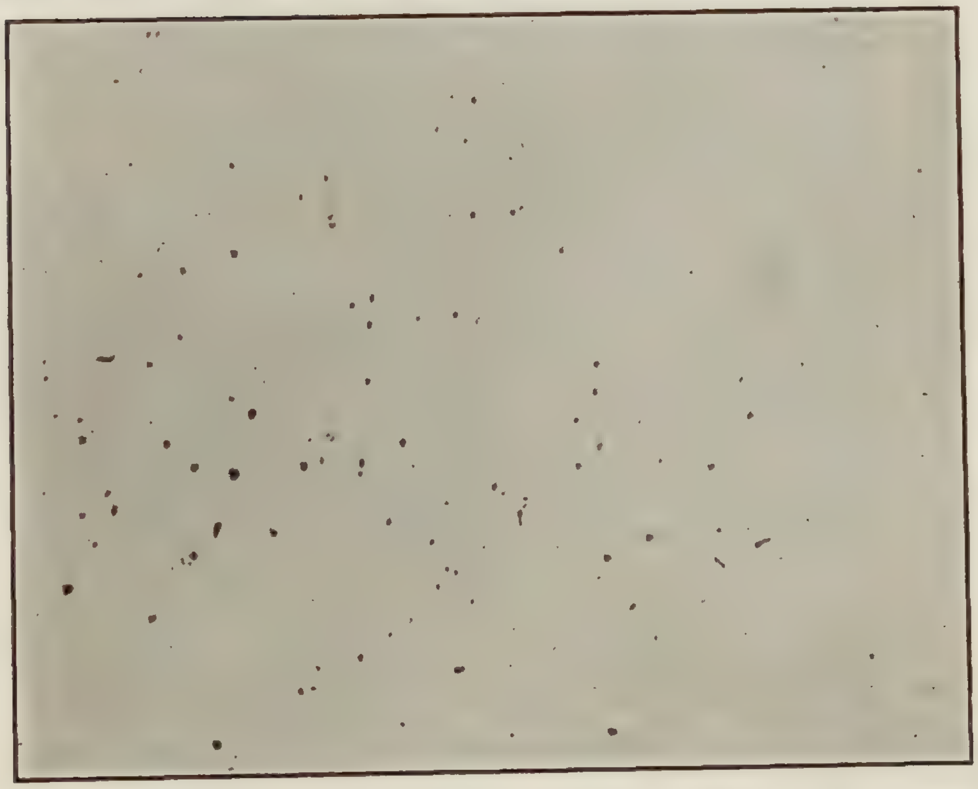


FIG. 6.—Mag. 100 ×. Microstructure of an alloy which was completely disintegrated in a few days

from the point in question and because of the limit of magnification imposed by the fact that the specimen was immersed in salt water. If they were metallic constituents they were very small—much smaller than either the aluminum or silicide particles normally observed in the same alloy.

The microstructure of the alloys varied between that shown in Figure 5 and that of Figure 6. Silicide and aluminum constituents were present, usually in small amounts, and under the microscope these constituents were found to be absolutely inactive. The hard particles in Figure 6 which were scattered through the alloys were also inactive unless the cathode areas might possibly be an occasional one of these particles. However, if such was the case it is estimated that not more than one out of fifty or a hundred were active. During the examination of these alloys literally thousands of these particles have been observed from which no hydrogen was liberated.

When pitting commenced the pits followed the tarnish pattern and the magnesium-rich dendrites were eaten out. As the attack advanced along the surface of the tarnished dendrite a stream of hydrogen bubbles always came from the part being dissolved, and the hydrogen liberated from the direct attack of the dendrite was greater than that coming from the cathode areas. The way in which pitting follows the tarnished areas is shown in Figure 8. In the upper left-hand corner of this micrograph may be seen a hexagonal or six-pointed star; at the extreme right a similar figure is observed in which five of the points are eaten out and the sixth (pointing toward the center of the micrograph) is tarnished. These star-shaped corrosion patterns are characteristic in the alloys showing dendritic corrosion pits.

Figure 9 shows an almost perfect dendrite in a specimen which has been repolished to remove the tarnish pattern. The polishing was then carried further to see if any constituent would be found at the bottom of the pits from which hydrogen could be liberated, but none was found. A typical area is shown in Figure 10. During the eating out of the magnesium-rich dendrites both silicide and aluminum constituents were inactive, as had been previously observed in the formation of the tarnish pattern.

There was little doubt that the dendrites developed both by tarnish and by pitting were those of primary magnesium or, rather, magnesium-rich solid solution. Six-pointed stars are characteristic of both hexagonal and trigonal crystal systems, and are observed in substances known to be hexagonal. There was evidently a connection between the large number of six-pointed corrosion pits and the hexagonal crystal structure of magnesium.

The form of the primary magnesium dendrite is shown in Figure 11. Here the dendrite is surrounded by eutectic and two constituents are present in the alloy. In the solid solution alloys the aluminum is dissolved, but there is sufficient difference in composition between the magnesium-rich dendrites which solidify first and the remaining interstitial material which fills in between them for the cores to be first tarnished and then eaten out when the specimen is immersed in salt water. The hydrogen comes from the dendrite as if it were being dissolved by direct attack. A comparison of the tarnish pattern and corrosion pit in Figures 13 and 14 with the primary dendrite in Figure 11 will make evident the relation between coring and corrosion.

EFFECT OF UNDISSOLVED CONSTITUENTS ON CORROSION

The alloys examined in the preceding sections were practically homogeneous except for minor impurities and small amounts of undissolved constituents. Alloys having a more heterogeneous structure were next prepared to determine if any relation existed between segregation of undissolved constituents and pitting. The typical microstructure of such an alloy is shown in Figure 15. The cored magnesium-rich dendrites similar to the corrosion pits could be brought out by deep etching, as shown in Figure 16.

When these alloys were examined while immersed in salt water the type of corrosion was found to be identical with the purer magnesium-aluminum alloys containing only one constituent. There were numerous cathode areas, but the magnesium-rich dendrites were eaten out as before and the attack was practically independent of the distribution of undissolved constituents. This is shown in Figures 17 and 20. All specimens did not show perfectly formed dendrites, but there was usually a similarity between the form of the corrosion pit and that of primary magnesium, as illustrated in Figures 19 and 20.

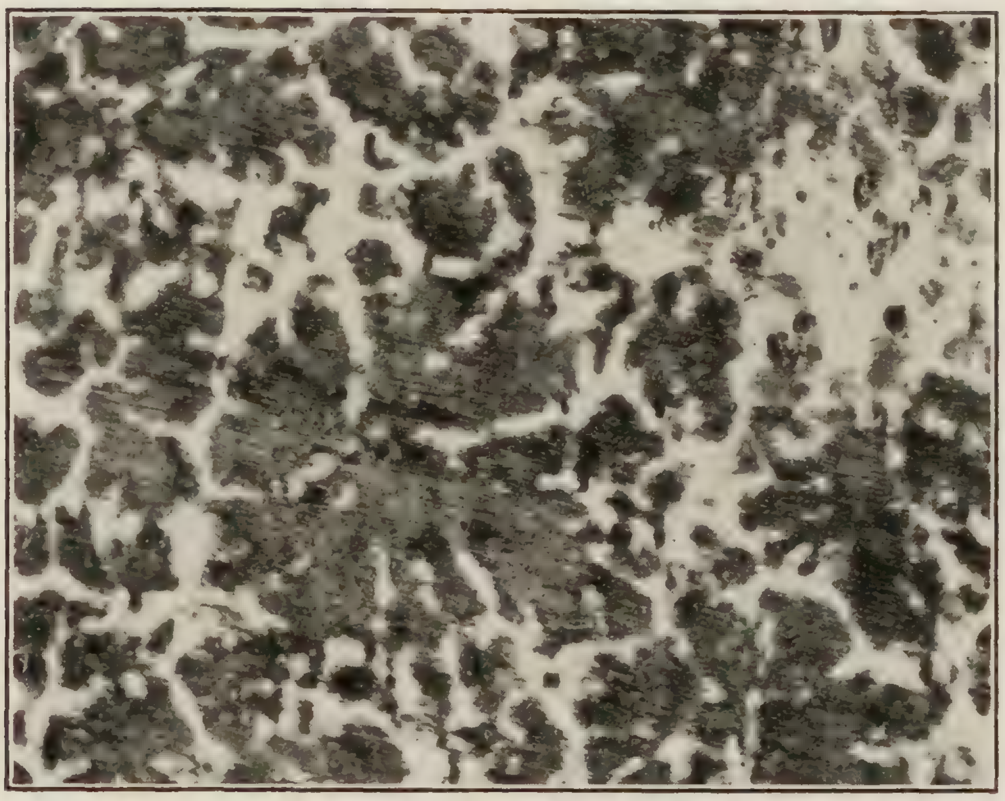


Fig. 7.—Mag. 100 ×. Tarnish pattern on polished surface of magnesium-aluminum alloy after immersion in salt water

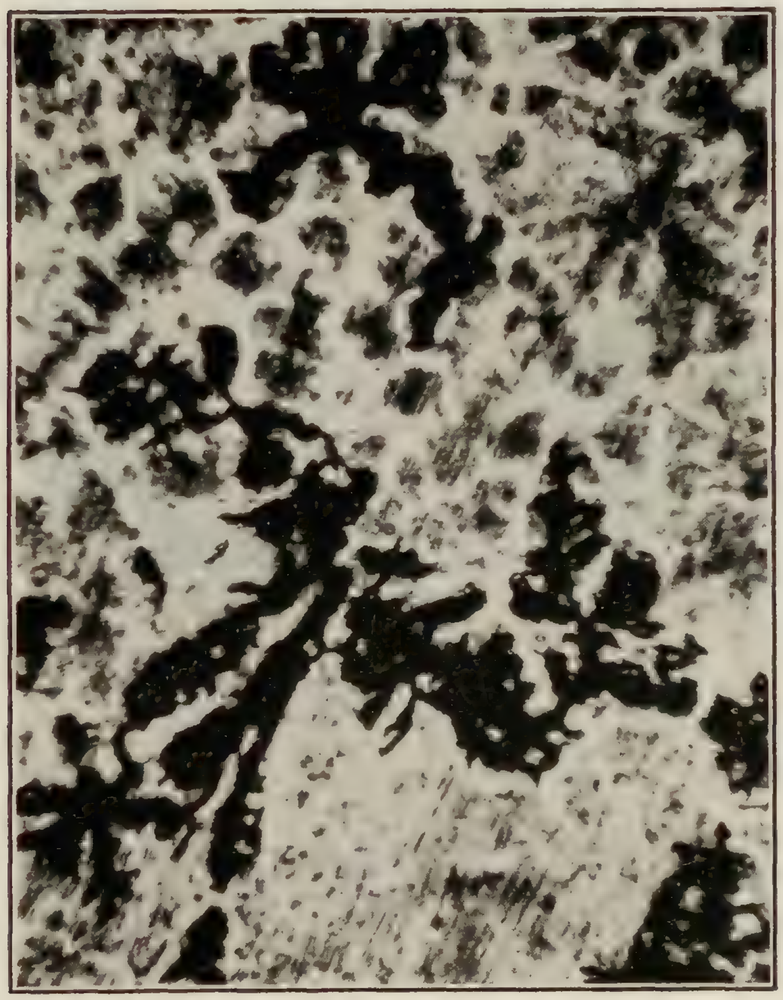


Fig. 8.—Mag. 100 ×. Showing how corrosion pits follow the tarnish pattern. Note the two hexagonal stars, upper left corner and right center

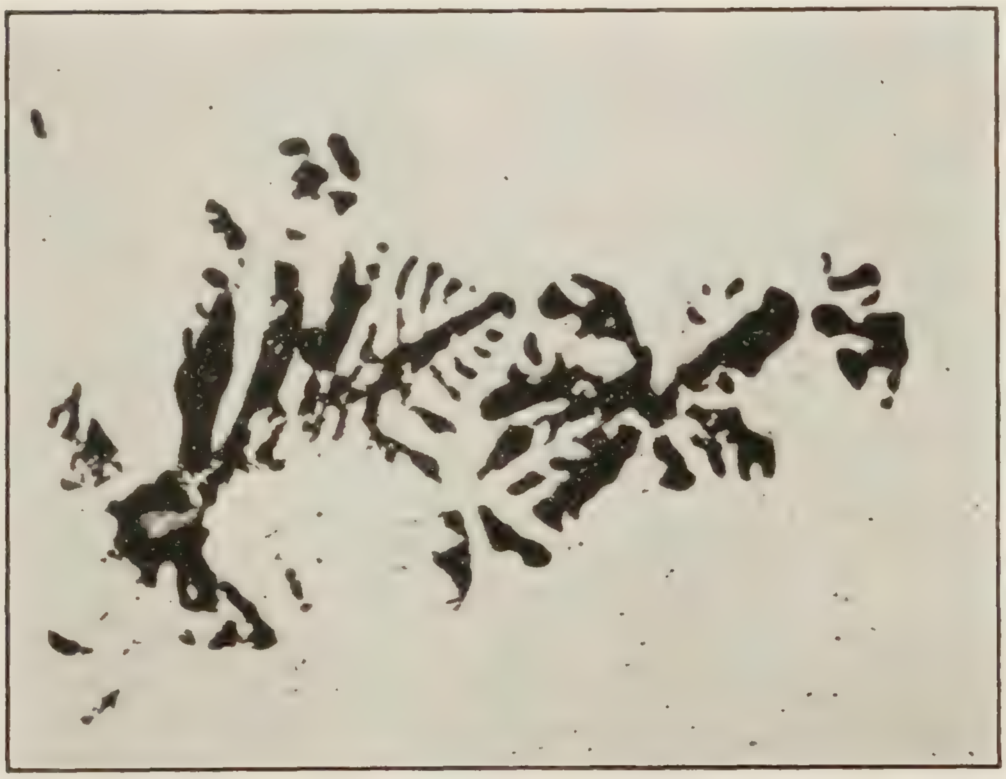


FIG. 9.—Mag. 100 ×. Dendritic corrosion pits in magnesium-aluminum alloy after repolishing

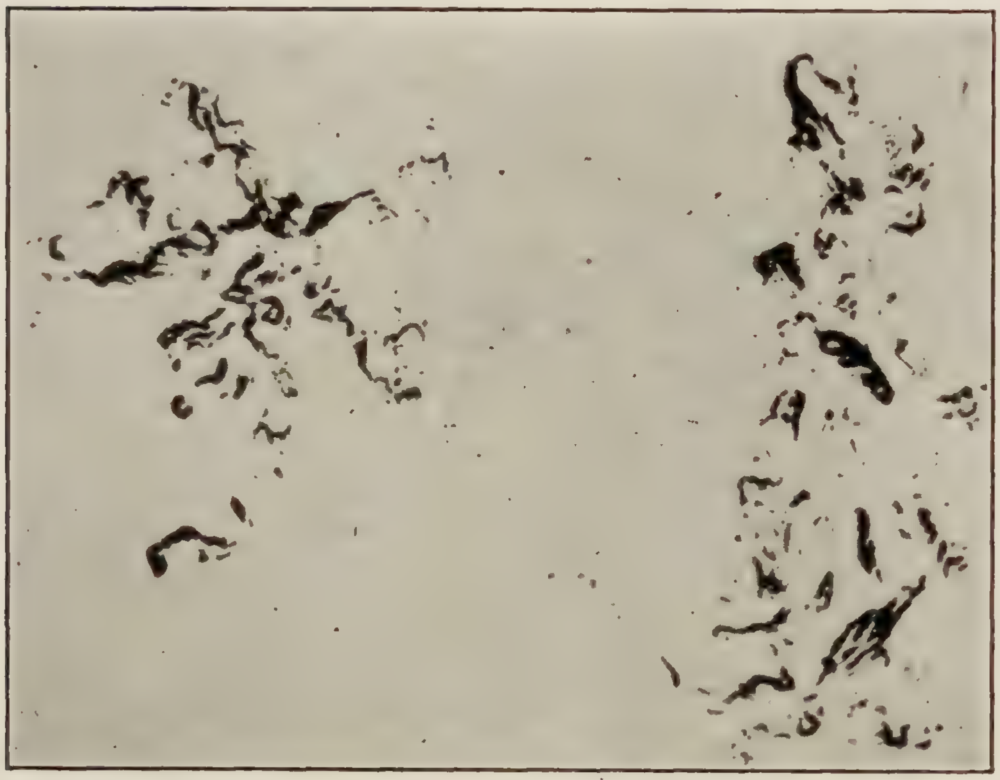


FIG. 10.—Mag. 100 ×. Bottom of corrosion pits in a 3 per cent aluminum alloy showing the absence of undissolved constituent or segregated impurity

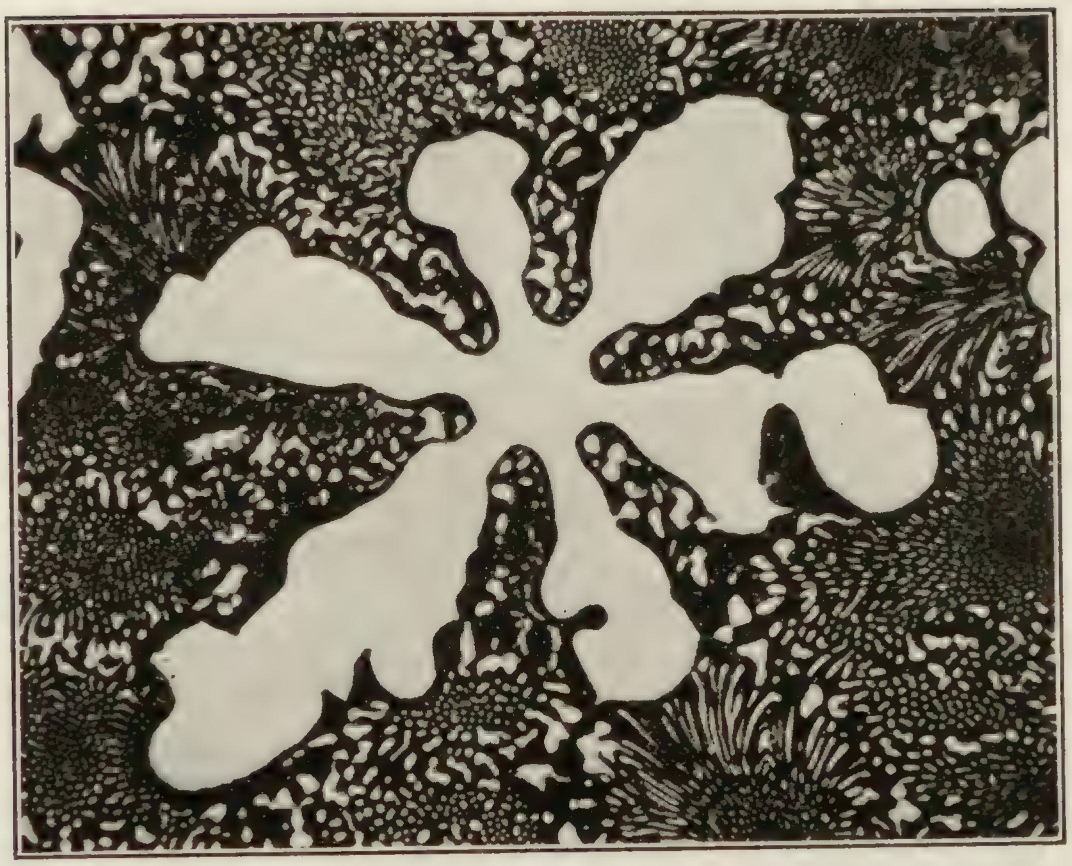


FIG. 11.—Mag. 100 ×. Primary magnesium dendrite in an alloy containing 30 per cent aluminum

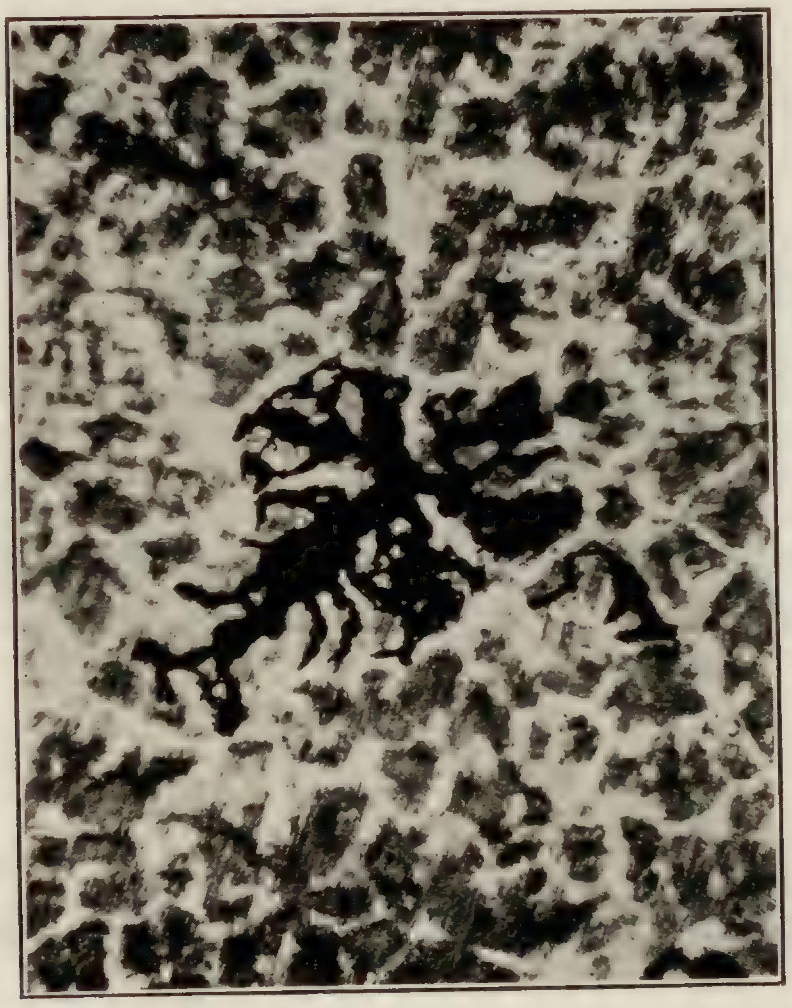


FIG. 12.—Mag. 75 ×. Corrosion pit in 3 per cent aluminum alloy

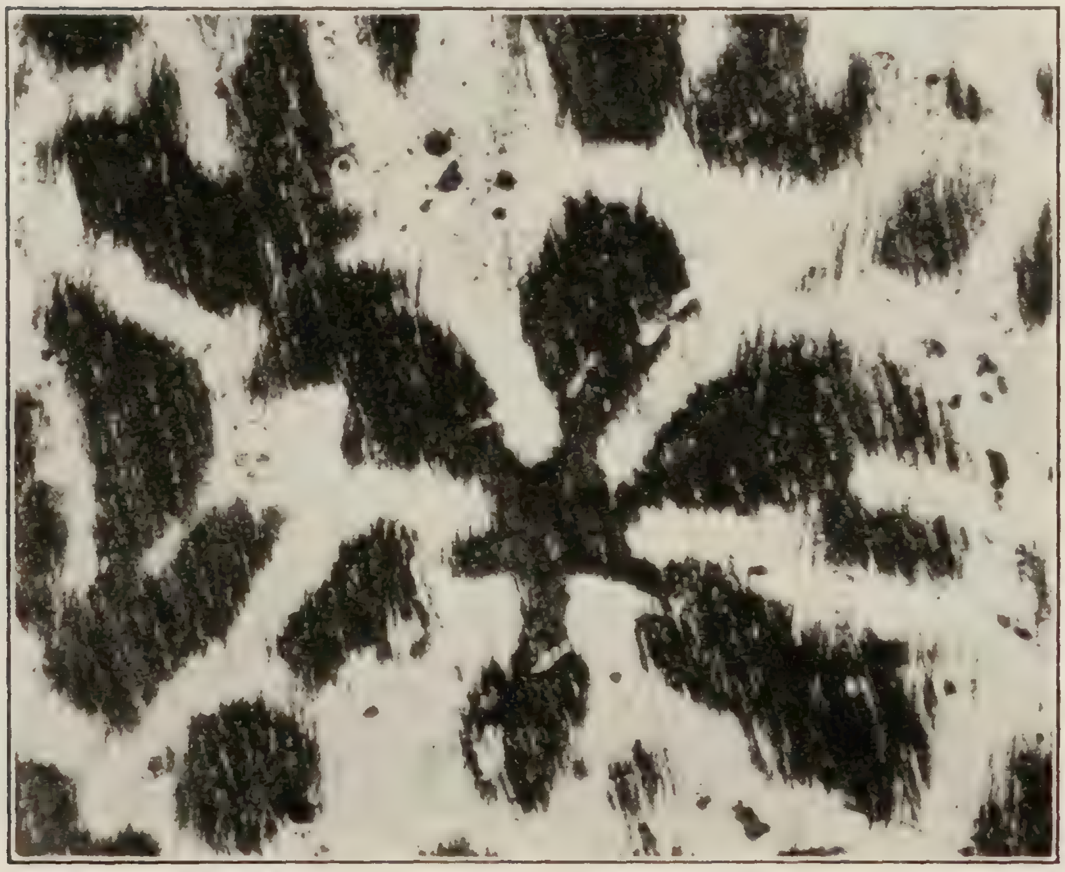


FIG. 13.—Mag. 100 ×. Tarnish pattern on polished surface of solid solution alloy (3 per cent aluminum) after immersion in salt water. Compare with Figure 11

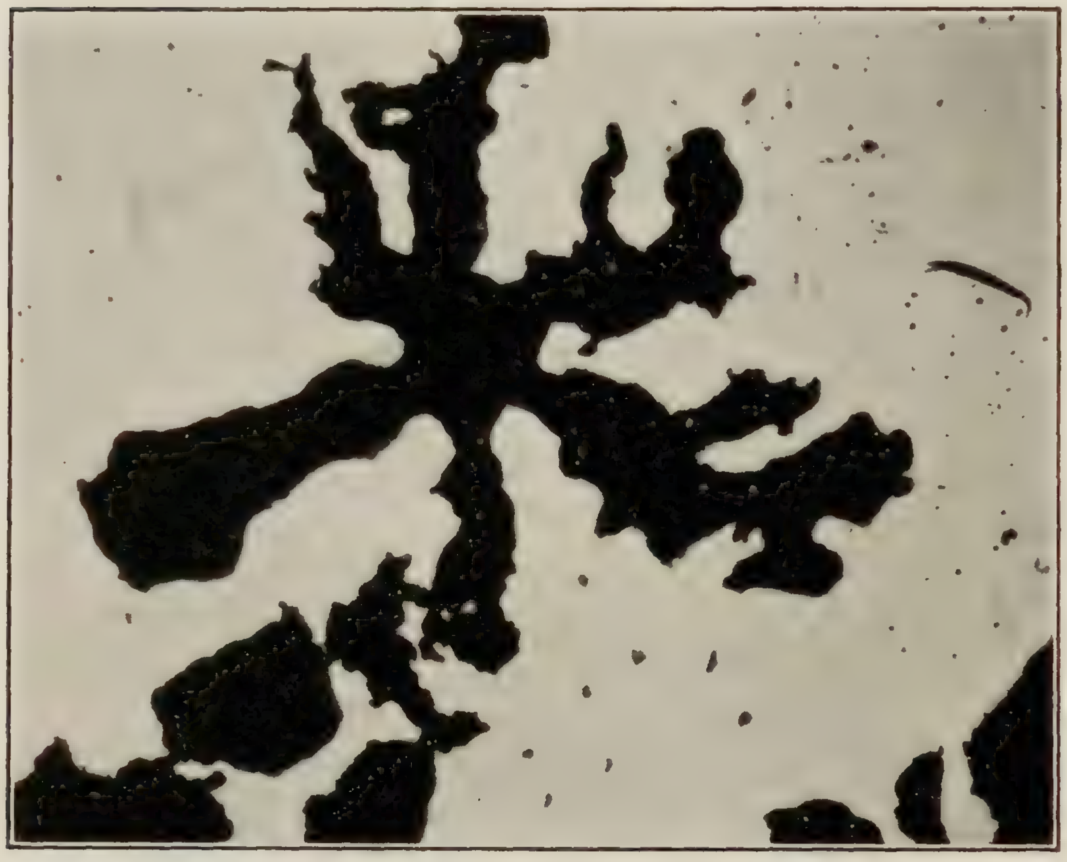


FIG. 14.—Mag. 100 ×. Corrosion pit in the alloy in Figure 13

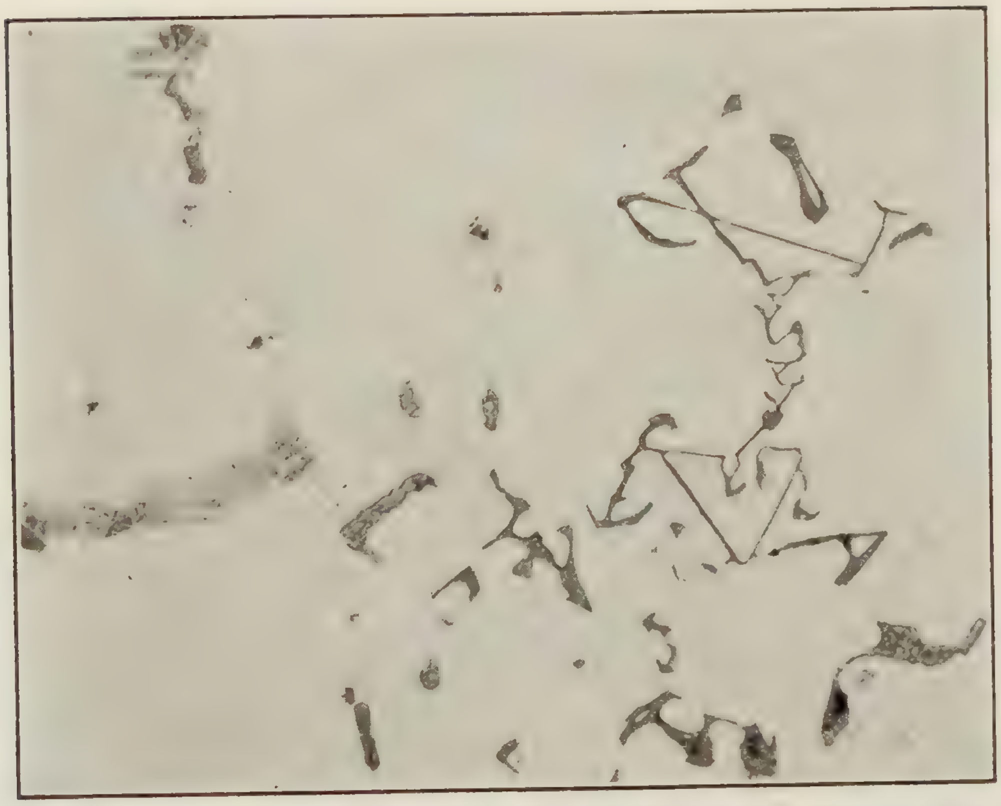


FIG. 15.—Mag. 200 ×. Microstructure of an alloy containing 5 per cent aluminum, 0.3 per cent silicon, balance magnesium

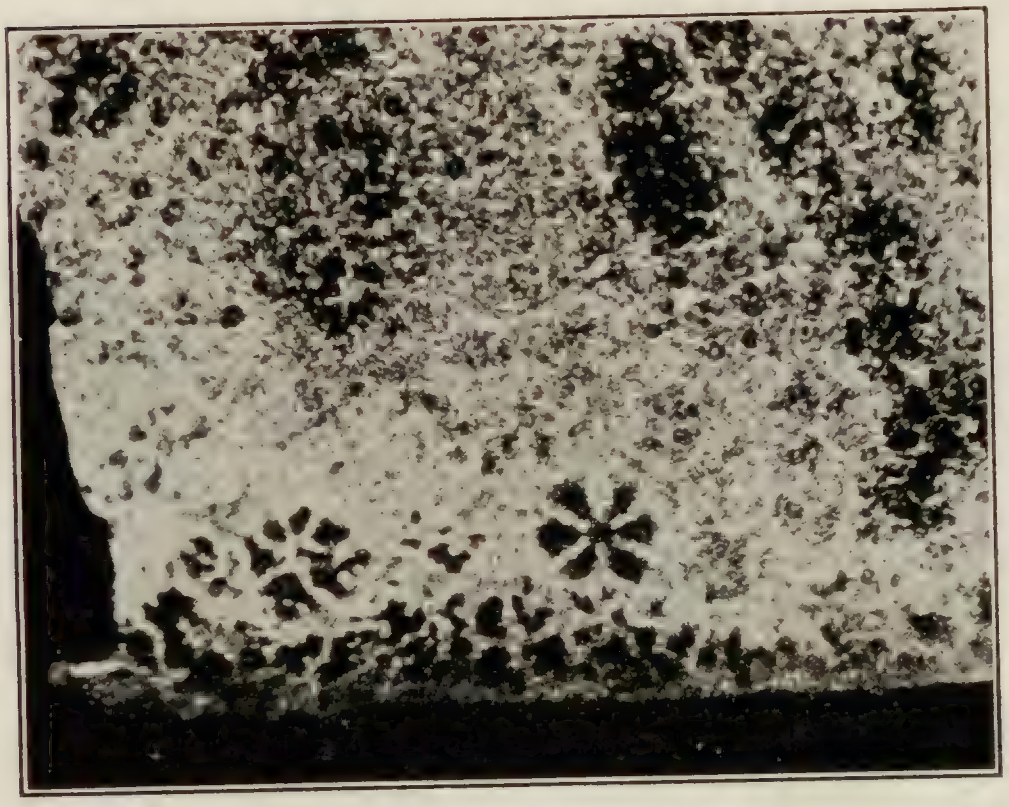


FIG. 16.—Mag. 50 ×. Cored magnesium-rich dendrite in same alloy as Figure 17, brought out by deep etching

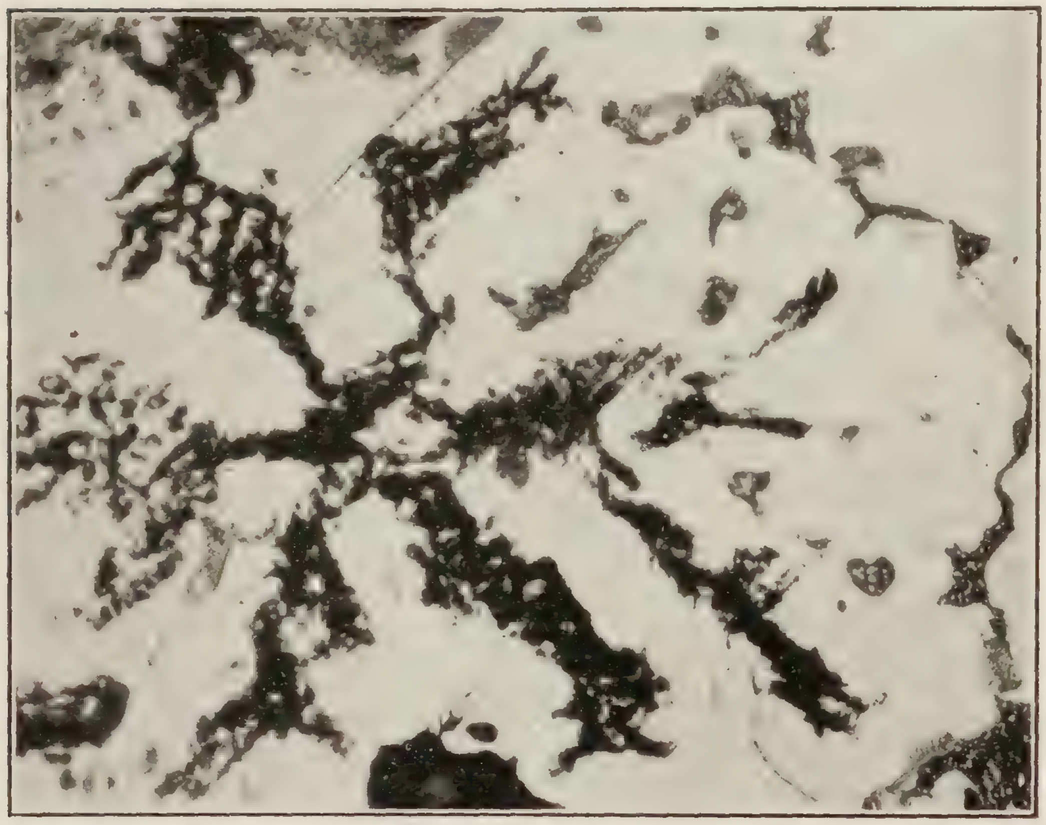


FIG. 17.—Mag. 200 ×. Corrosion pit in the alloy containing 5 per cent aluminum and 0.3 per cent silicon. The cored magnesium-rich dendrite was eaten out, while both the silicide and aluminum constituents remained inactive

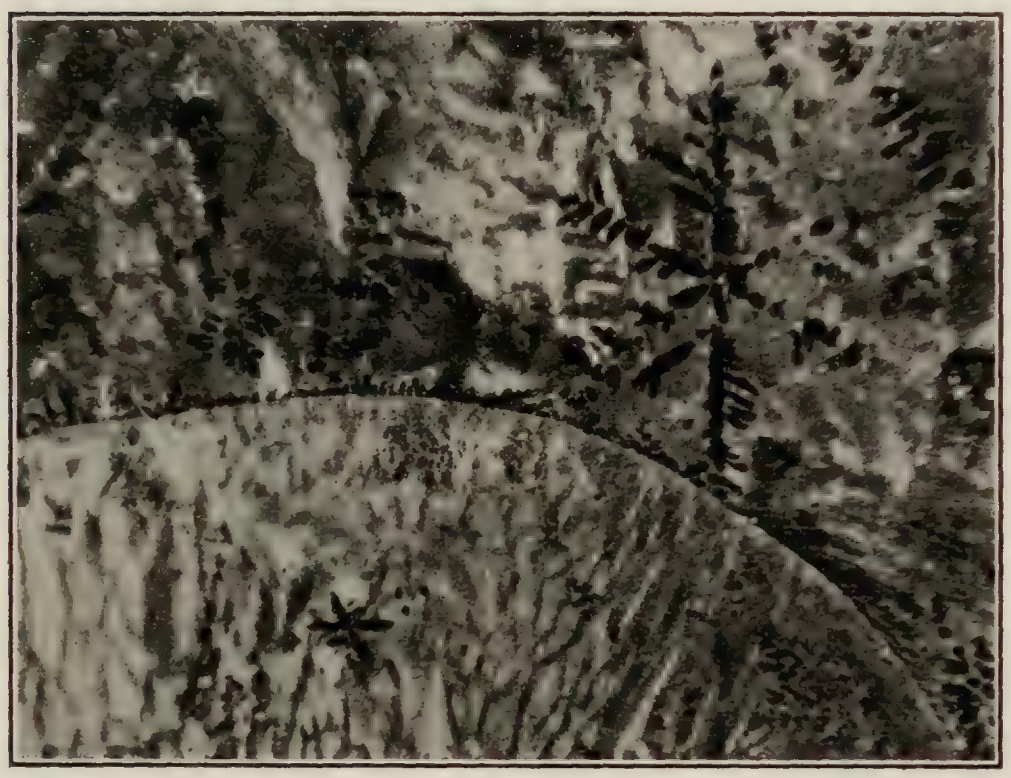


FIG. 18.—Mag. 50 ×. Primary dendrite of magnesium in an alloy containing 3 per cent silicon. Note the identical form with corrosion pit of Figure 17

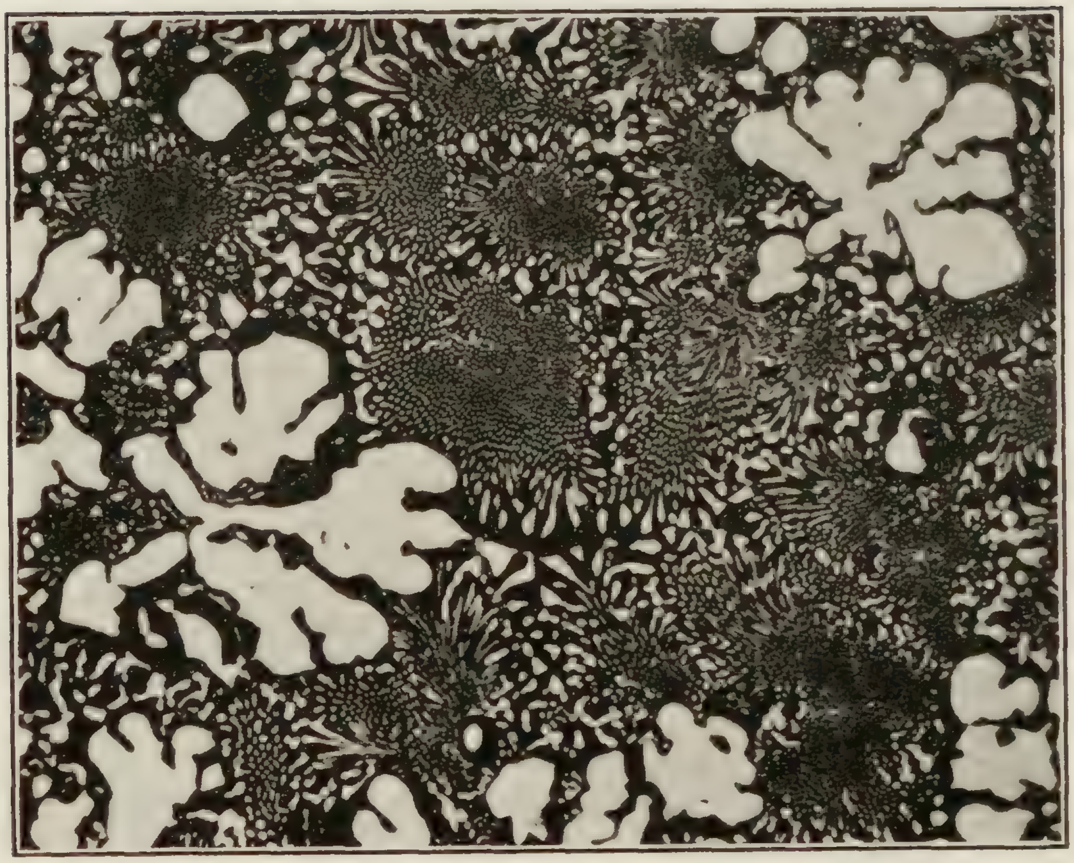


FIG. 19.—Mag. 100 ×. Primary magnesium in an alloy containing 30 per cent aluminum

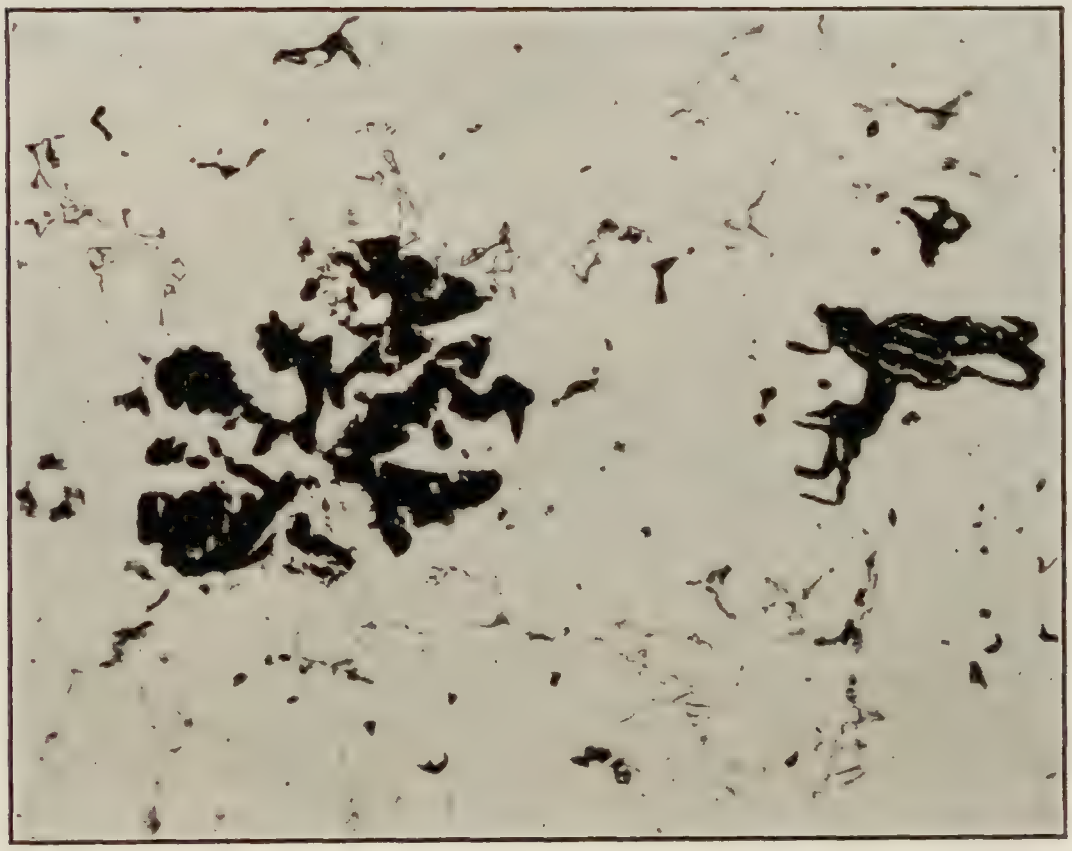


FIG. 20.—Mag. 100 ×. Corrosion pits in an alloy containing 5 per cent aluminum and 0.3 per cent silicon, showing that corrosion attack is independent of the distribution of undissolved constituents and also similarity in form of pits to primary magnesium, Figure 19

THE CORROSION OF EXTRUDED METAL

The corrosion attack on the polished surface of extruded metal furnished additional evidence that the initial pitting bore a definite relation to the structure of the metal. The nature of the attack was almost identical with that of the cast alloys; the hydrogen came from the pits as they were being eaten out, and it was possible to observe the stream of hydrogen bubbles advance along the surface of the metal as the attack progressed. The amount of hydrogen liberated from the small cathode areas or particles was small in comparison.

In the longitudinal section the corrosion pits were all straight lines parallel to the direction of extrusion, as shown in Figure 21. The corrosion attack of the transverse section was irregular and did not have a directional tendency. The cored areas were presumably drawn out into a more or less fibrous structure and their original dendritic form was lost.

PROOF OF THE RELATION BETWEEN CORING AND CORROSION

After the metallographic study of corrosion had been practically completed, an etch was found which developed the cored structure of the alloys by tarnishing rather than by deep etching. In this way it was possible to bring out even the finer details of the cored dendrites. In a number of cases the etch was so sharp that the cores had the appearance of a second constituent, but this was rendered improbable by their disappearance on prolonged annealing. The size of the magnesium-rich areas depended to a considerable extent on the time of etching and the strength of the acid used, which would not be the case if the cores were a second constituent. Furthermore, the form of the cored dendrites was identical with that of the magnesium dendrites in the higher alloys containing eutectic.

When the specimens which had been corroded in salt water and then repolished to remove the tarnish film were etched to bring out the cored structure it was found that the corrosion pits were superimposed on the magnesium-rich cores, as shown in Figure 24.

The tarnish pattern brought out by the action of salt water showed that manganese did not change the dendritic structure of the magnesium-aluminum alloys (fig. 25). The type of corrosion was similar to that of the binary alloys without manganese, except that the tarnished dendrites did not have as great a tendency to be eaten out. The cored structure would also be developed by etching, as shown in Figure 26.

COMPARISON OF THE CORROSION OF CHILL-CAST AND SAND-CAST SPECIMENS

The metallographic study up to this point had established a definite relation between coring and the corrosion attack by salt water. It was not known whether coring actually caused corrosion by the establishment of differences in potential between the various parts of the alloy or whether the magnesium-rich dendrites were preferentially attacked merely because of their higher solution potential. The presence of manganese was necessary to keep the dendrites from being eaten out, and it was proposed to examine a chill cast aluminum alloy containing manganese which was not resistant to salt water, to determine if coring were the cause of its lack of resistance. If so, suitable heat treatment to eliminate differential composition should produce a favorable change in corrosive properties.

The alloy chosen was specimen No. 7 of the corrosion test shown in Figures 3 and 4. This alloy differed from the three resistant test specimens by being chill cast while the others were cooled fairly slowly; it was also air cast and contained included films, while the resistant alloys were vacuum cast; in addition, it was slightly low in manganese. It was believed that the examination to determine whether coring was the cause of corrosion would also determine the influence of the other two factors by a process of elimination.

On polishing a cross-section of half the ingot, it was found that chill casting had a marked effect on the distribution of the corrosion attack. The corroded specimen is shown in Figure 27. The specimen is slightly reduced in size and is shown by oblique illumination; the corroded areas appear light and the polished surface dark. The area around the chilled edge is corroded almost uniformly to an extent of about half an inch; the cut edge, which shows as a heavy

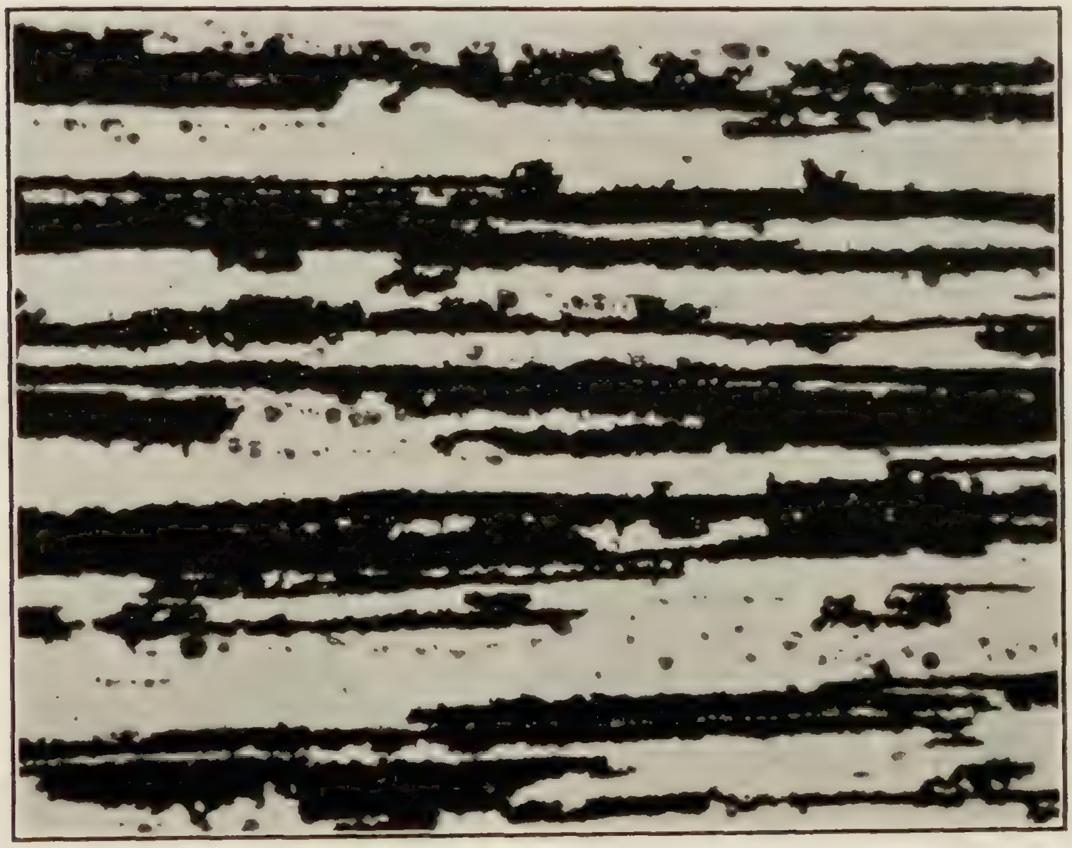


FIG. 21.—Mag. 100 ×. Corrosion pits in alloy containing 4 per cent Al, 0.2 per cent Mn, extruded, longitudinal section. The cores have been drawn out into a fibrous structure

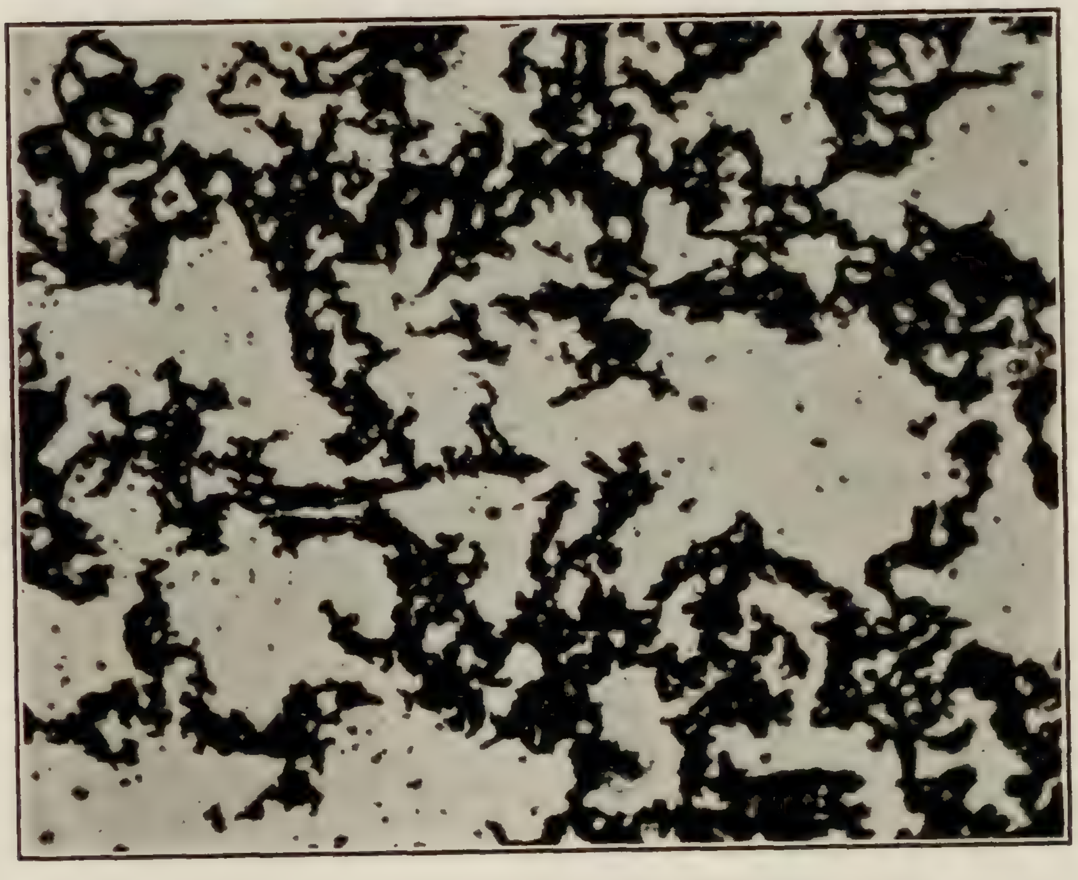


FIG. 22.—Corrosion pits in transverse section of extruded alloy. Note the absence of a directional tendency

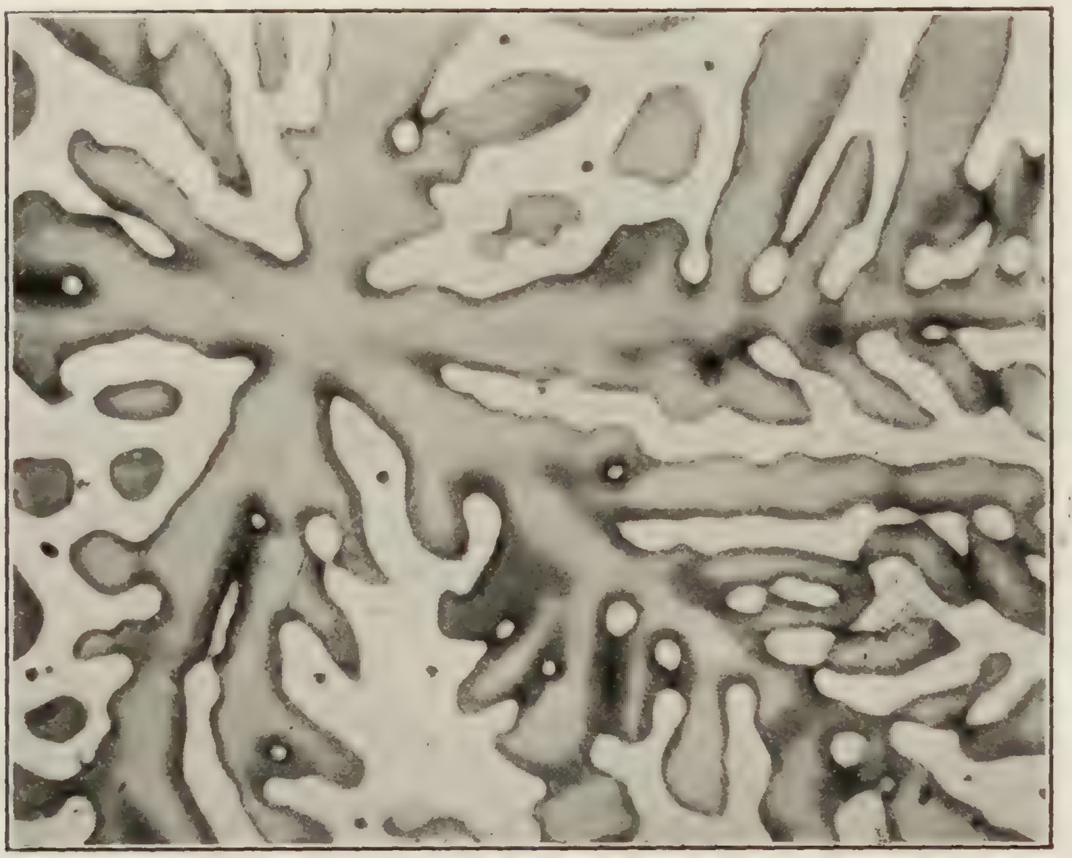


FIG. 23.—Mag. 100 ×. Cored dendrite in 3 per cent aluminum alloy

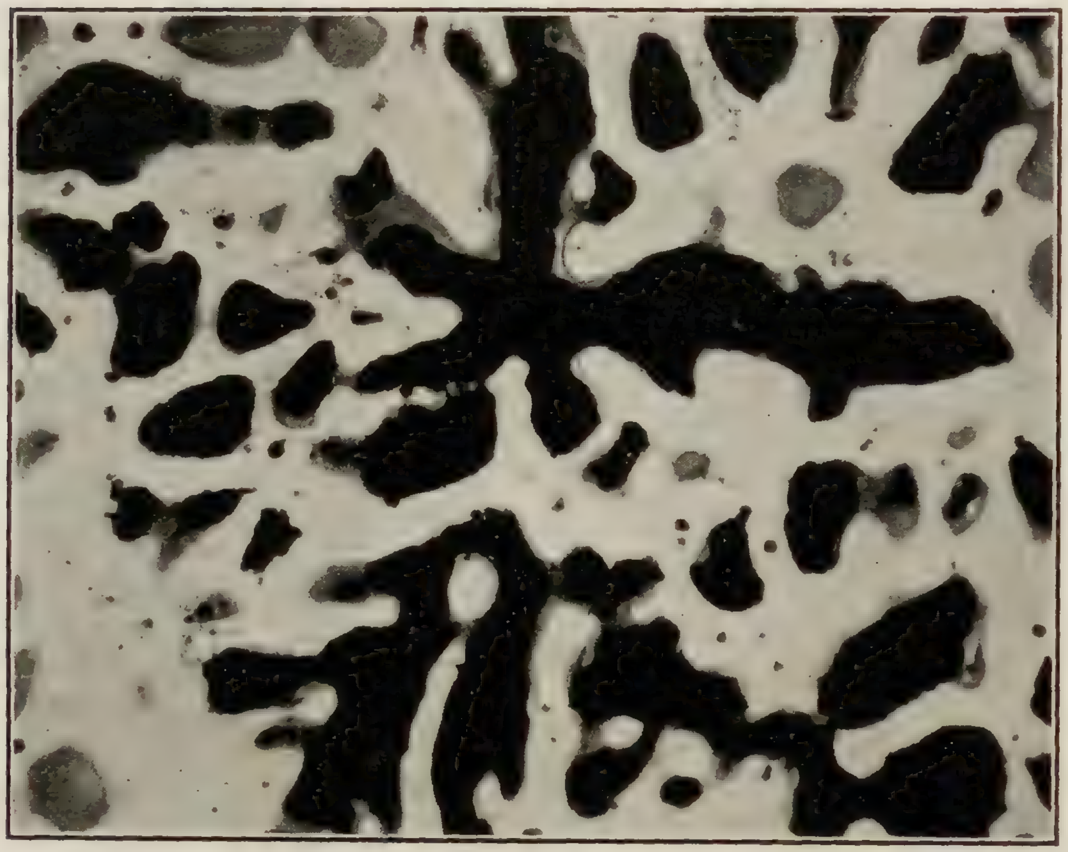


FIG. 24.—Mag. 100 ×. Corrosion pits in the alloy of Figure 23. Specimen was repolished and etched after corrosion. Corrosion pits black; cored dendrites halftone

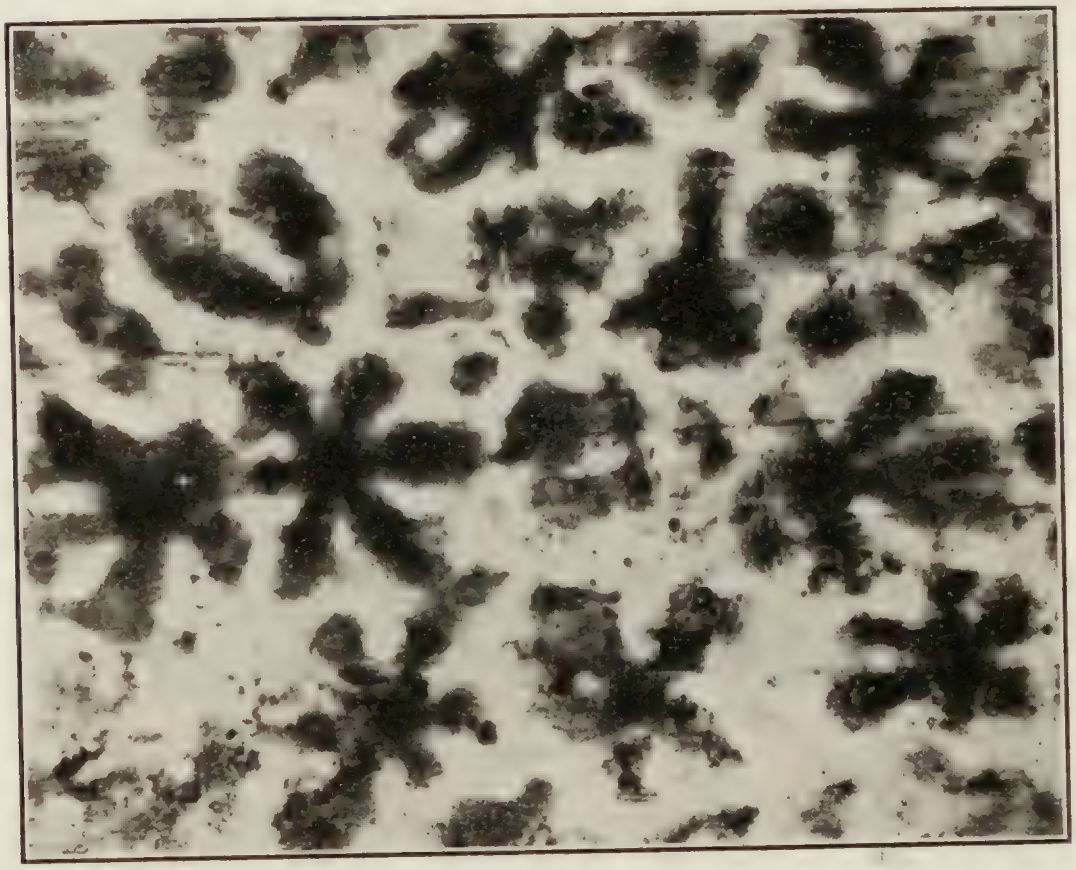


Fig. 25.—Mag. 100 ×. Tarnish pattern of magnesium-aluminum alloy containing 0.3 per cent manganese

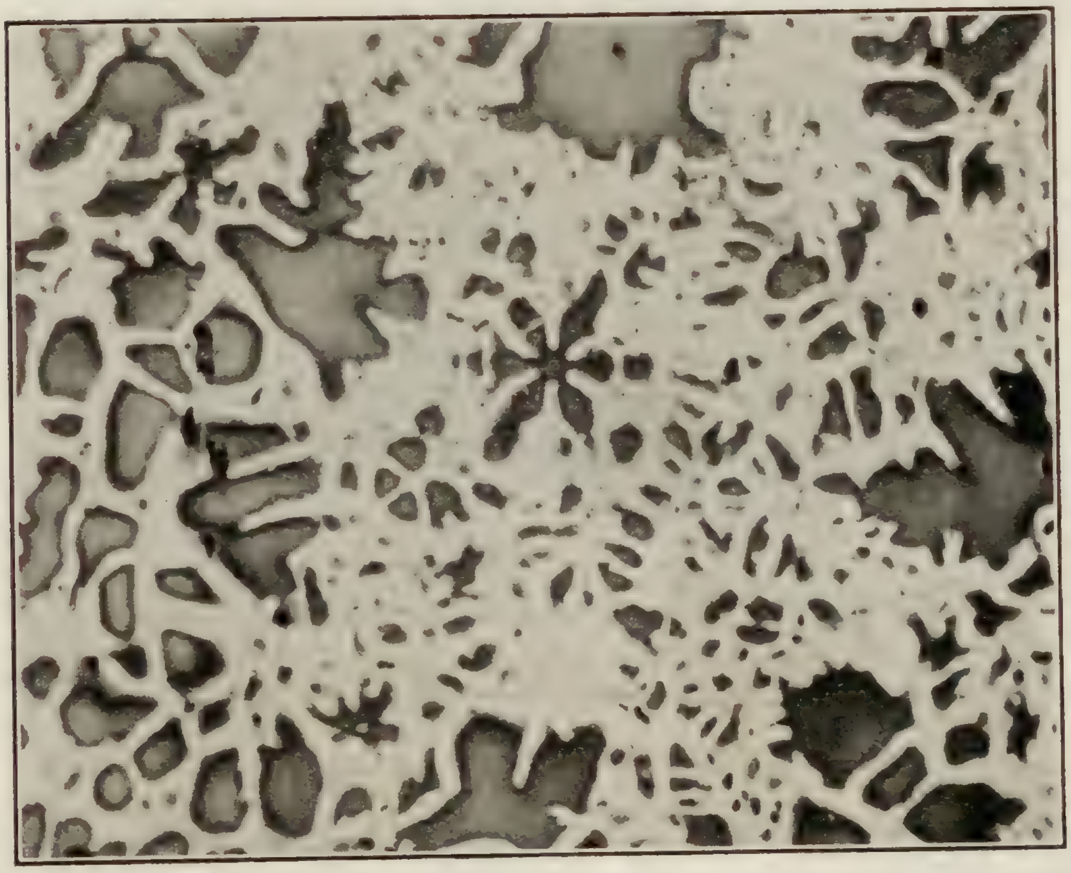


Fig. 26.—Mag. 100 ×. Cored structure of magnesium-aluminum alloy containing 0.3 per cent manganese

white line because it catches the oblique illumination, is not pitted at all. Here again is a reproduction on a large scale of the corrosion attack observed microscopically; the first part of the alloy to solidify, in one case the chilled edge and in the other case the cored dendrite, is attacked preferentially and this attack is practically independent of the distribution of metallic constituents or nonmetallic inclusions. A sand-cast specimen, corroded at the same time for comparison, was uniformly pitted (fig. 29).

FIG. 27.—Corrosion of chill cast magnesium-aluminum alloy containing 0.2 per cent Mn

Figure 28 shows the two halves of the specimen, the left half as cast and the right half annealed for five days at 400° C. In the heat-treated specimen the dendritic attack, running from the outer edge in tree-like fashion, was absent but it appeared that whole grains were eaten out. Resistance to corrosion was not bettered. When extruded pieces of the same alloy were given a similar heat treatment and tested quantitatively for corrosion they were found to even be worse than before heat treatment.

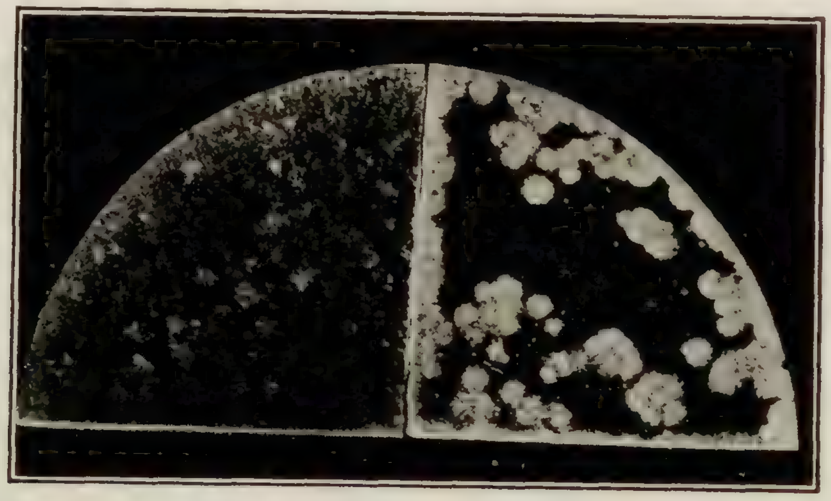


FIG. 28.—Same specimen as Figure 27. Left half as cast; right half annealed five days at 400° C.

Hence it could be concluded that coring was not the cause of corrosion. Observations made during this same experiment also indicated that included oxide films had little effect. The problem seemed to be narrowed down to the effect of the manganese content.

EFFECT OF NONMETALLIC INCLUSIONS ON CORROSION

Metallographic examination frequently indicated a relation between corrosion and nonmetallic inclusions. The corrosion attack tended to follow along entrained films, and inclusions were frequently surrounded by corrosion pits. It seemed probable that the presence of nonmetallic inclusions was responsible for the rapid corrosion of a number of nonresistant air cast alloys. However, when corrosion was observed under the microscope the inclusions were found to be inactive. In some cases no action occurred at or near the inclusions; in other instances the films were surrounded by corrosion pits, but the attack frequently started at some distance from the inclusion and corrosion did not proceed from the inclusion outward.

Etching to develop cored structure showed that the relation between films and inclusions and corrosion was only apparent. The inclusions act as nuclei for the solidification of the magnesium-rich cored centrites, as shown in Figure 30. As the inclusion becomes larger the dendrite loses it symmetry and tends to branch out at right angles from the edge of the inclusion to which it is attached. When the specimen is immersed in salt water the magnesium-rich cores are attacked, leaving the inclusion surrounded by a corrosion pit. This type of corrosive action is illustrated in Figure 31.

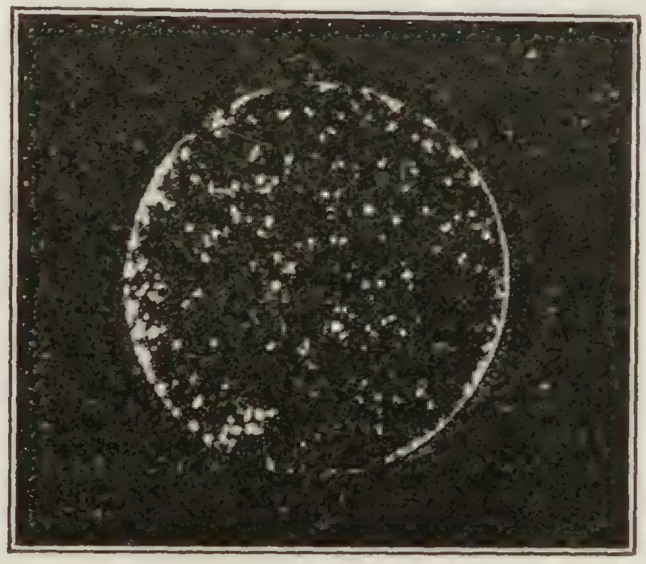


FIG. 29.—Corrosion pits in polished specimen of sand cast alloy containing 0.4 per cent manganese

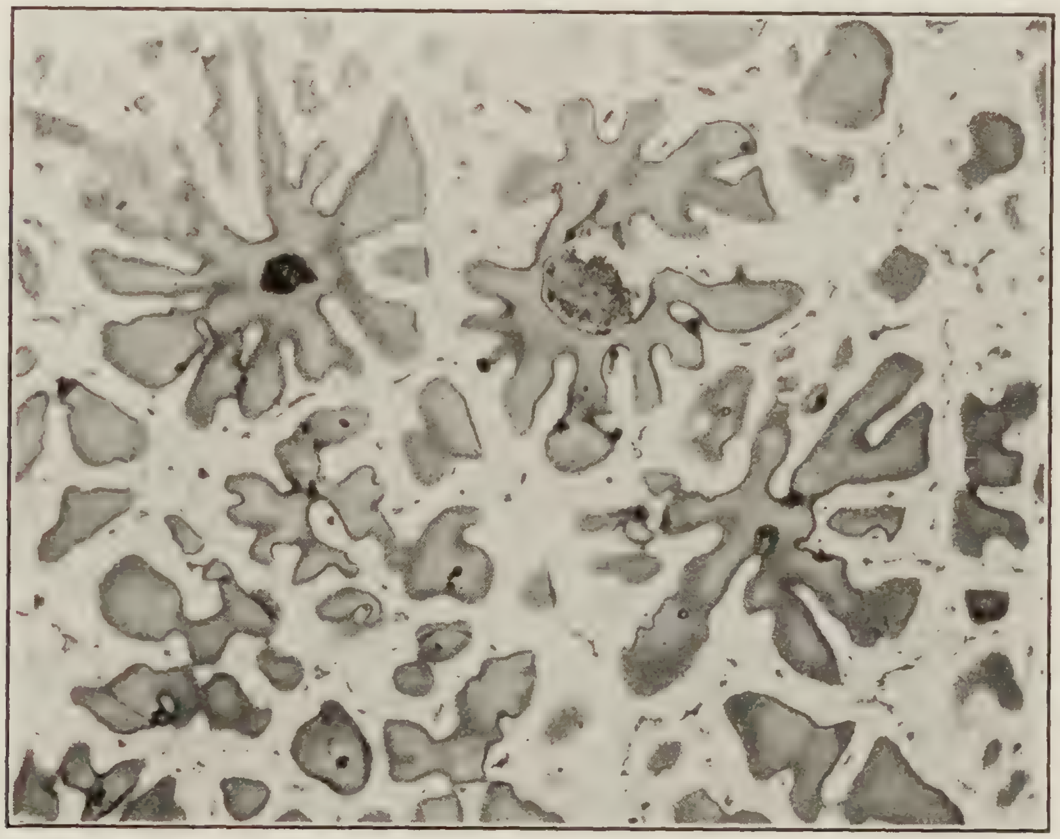


FIG. 30.—Mag. 100 ×. Cored magnesium-rich dendrites surrounding nonmetallic inclusions

EFFECT OF VARYING THE MANGANESE CONTENT

A series of corrosion tests was made to determine the effect on corrosion of varying the manganese content of the 4 per cent aluminum alloy. The specimens were tests bars which had been previously broken in tensile tests, and were machined to present a clean surface. A 2 per cent sodium chloride solution was used, and the results after five days' immersion are shown in Figure 32.

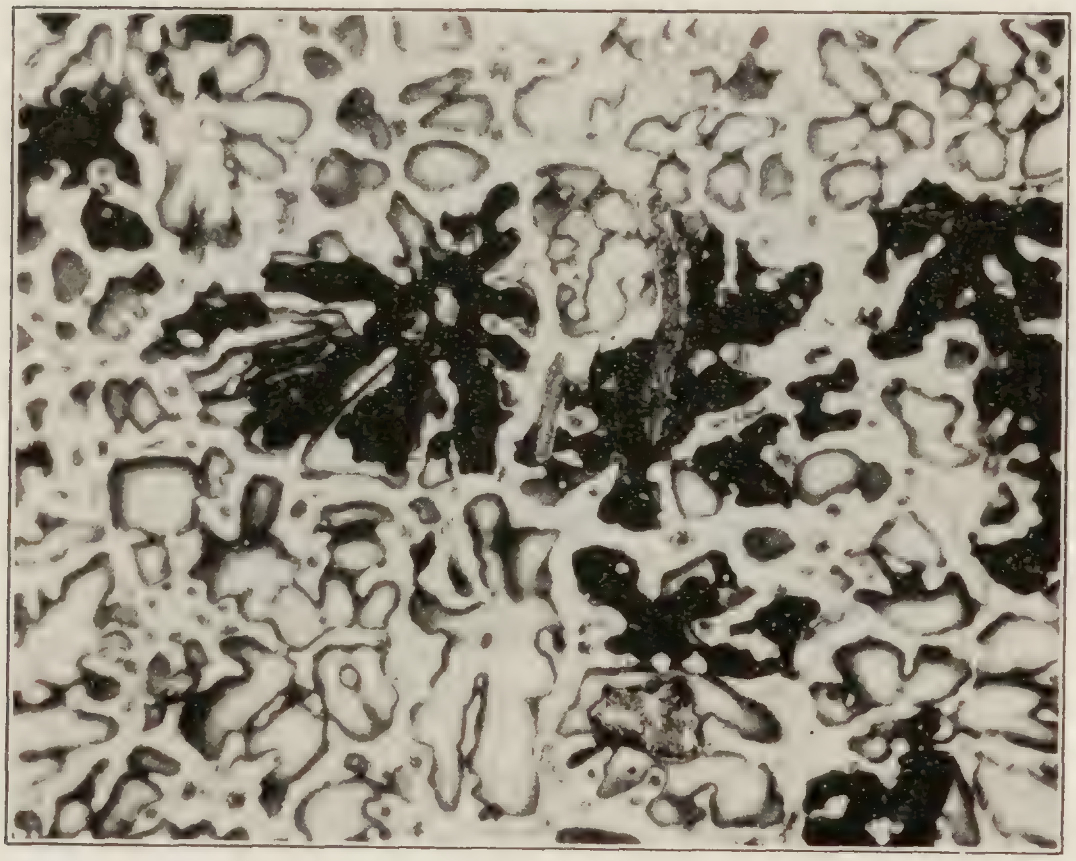


FIG. 31.—Mag. 100 ×. Corrosion in area containing inclusions, showing relation between pitting and cored structure

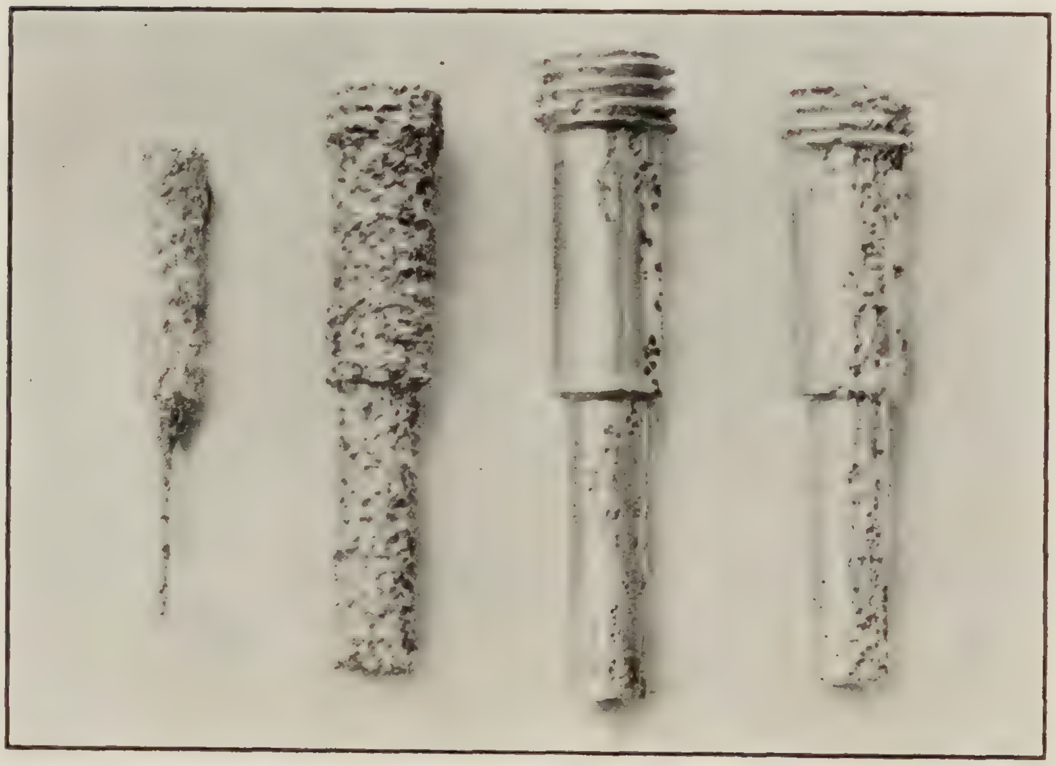


FIG. 32.—Effect of varying the manganese content of the 4 per cent aluminum alloy

1. 0.10 per cent Mn
2. 0.22 per cent Mn
3. 0.36 per cent Mn
4. 0.66 per cent Mn

All as extruded; five days' immersion, 2 per cent NaCl solution

It is evident from these tests that a critical amount of manganese is necessary to produce a maximum inhibiting effect. The alloys low in manganese were badly corroded. A few hundredths of a per cent will make all the difference between an alloy which corrodes rapidly and one which is resistant. In order to determine more accurately the effect of small variations, a series of alloys was made in which the manganese was varied by approximately .05 per cent intervals. The specimens were the standard corrosion test pieces, 3 x $1\frac{1}{8}$ inches x $\frac{3}{16}$ inch. After five days' immersion in 2 per cent sodium chloride solution the pieces were acid cleaned and weighed.

LOSS IN WEIGHT OF CORROSION TEST PIECES CONTAINING VARYING AMOUNTS OF MANGANESE

Composition	Loss in weight
Per cent	
.10 Mn (4 per cent Al)	19.1
.15	14.4
.19	11.3
.23	8.9
.28	3.2
.32	2.2
.38	1.7
.40	1.9

These specimens were made under argon and were not cast in a cold chill mold but were cooled fairly slowly. When the specimens were heat treated and quenched those containing too little manganese corroded much more rapidly than before heat treatment. The difference in varying the amount of manganese was comparable to that obtained in chill cast foundry alloys having a slightly low manganese content as compared with the resistant vacuum-cast alloys. It seemed probable that the difficulty in obtaining a resistant foundry alloy was due to the presence of too little manganese, so that the manganese content was raised to 0.35 per cent. When this was done, the corrosion tests on the foundry alloys showed the metal to be practically as resistant as that made under vacuum or argon.

It may be concluded that the manganese content should be at least three-tenths per cent, and preferably four-tenths per cent, to allow for difference in thermal treatment and the small variation usually encountered in preparing the alloy.

CORROSION TESTS OF THE ENTIRE SERIES SHOWING THE EFFECT OF VARYING BOTH THE ALUMINUM AND MANGANESE

Tests similar to those made with the 4 per cent aluminum alloy were run with alloys containing 6, 8, and 12 per cent aluminum. The results are shown in Figures 33 to 35. The specimens were ends of broken test bars which were machined again to present a fresh surface, and all samples were immersed for 48 hours in 2 per cent sodium chloride solution. At the conclusion of the test the specimens were acid cleaned by dipping for 20 seconds in dilute nitric acid.

As the aluminum content was increased it was evident that the amount of manganese must also be increased to assure an inhibiting effect in all stages of thermal treatment. Even the 12 per cent alloy, which ordinarily corrodes very rapidly, could be made as resistant as any of the others by the addition of a sufficient amount of manganese.

The photographs of the 6 and 8 per cent series show the extent to which corrosion was inhibited in the specimens containing sufficient manganese. The effect is not brought out as well in the 12 per cent series because the latter are turned black on acid cleaning and do not present a polished surface. On visual examination after corrosion the 12 per cent alloy specimens 6, 12, and 18 were found to be unattacked by salt water except for a black surface discoloration.

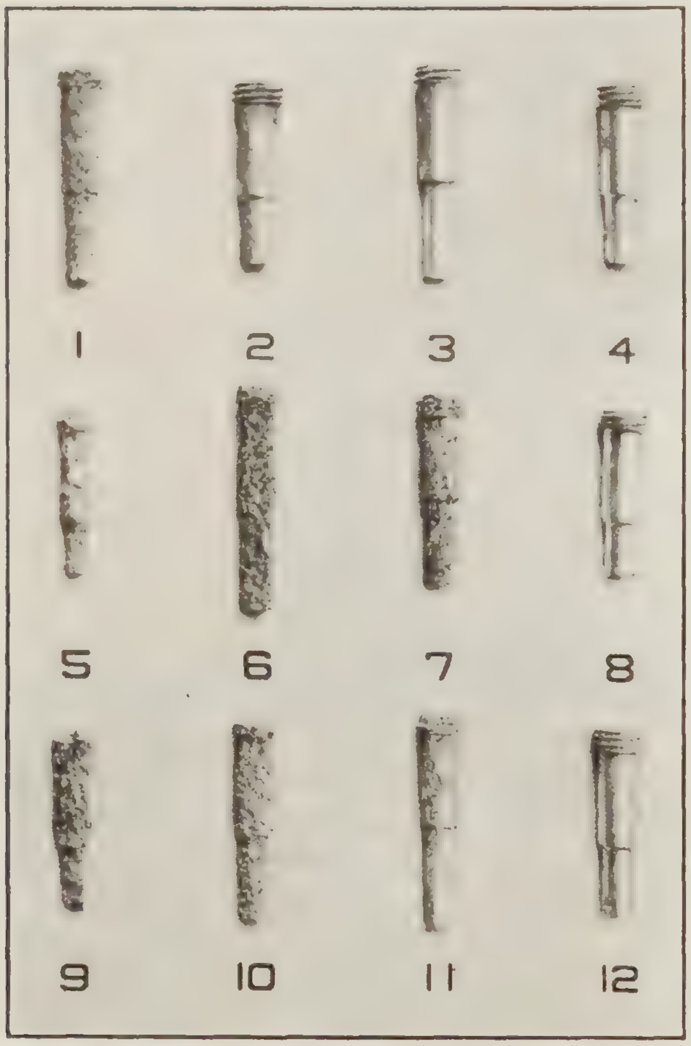


FIG. 33.—Corrosion tests of 6 per cent aluminum alloy containing varying amounts of manganese.

Spec. No.	Al	Mn
1	6.18	0.10
2	6.60	.20
3	5.91	.35
4	6.1	.57

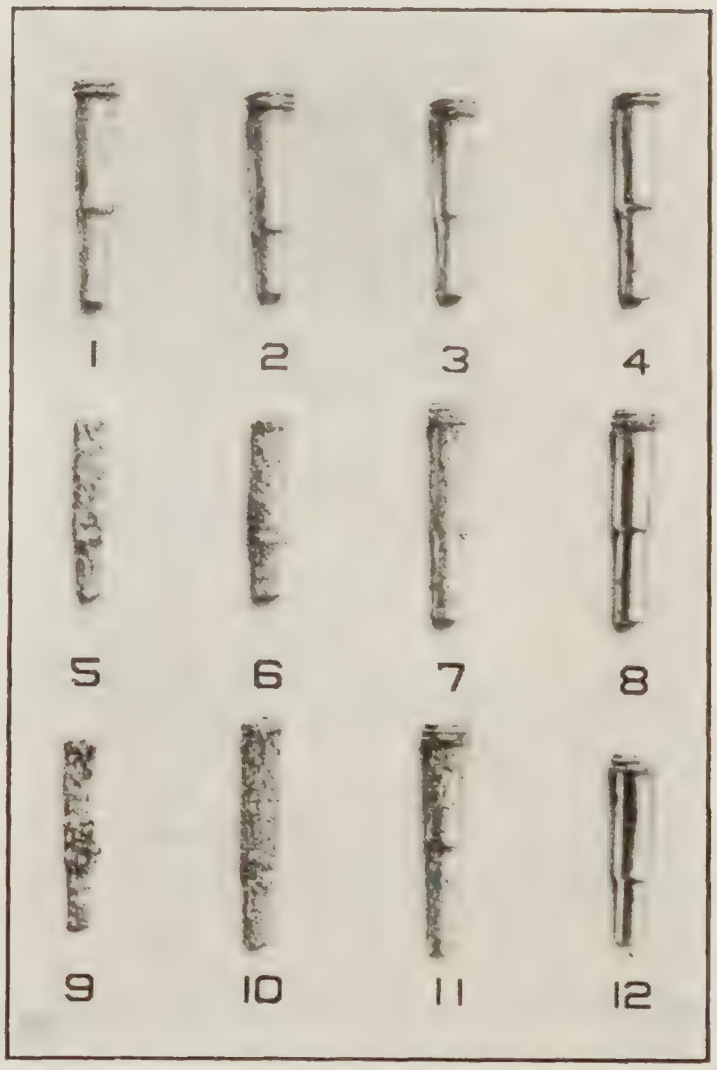


FIG. 34.—Corrosion tests of 8 per cent aluminum alloy containing varying amounts of manganese

Spec. No.	Al	Mn
1	8.61	0.12
2	7.86	.17
3	8.49	.42
4	8.18	.55

Specimens 5, 6, 7, and 8 heat-treated and quenched. Specimens 9, 10, 11, and 12 heat-treated, quenched, and aged. Immersed 48 hours, 2 per cent NaCl solution

EFFECT OF HEAT TREATMENT ON THE CORROSION OF THE ALUMINUM ALLOYS CONTAINING MANGANESE

It is interesting to note in the preceding tests that in every case where insufficient manganese is present solution heat treatment makes the alloys much less resistant to corrosion. It is evident that corrosion is not a question of homogeneity, as has also been confirmed by microscopic examination. The amount of manganese necessary depends apparently on the amount of aluminum in solid solution and not on that present as undissolved constituent. When sufficient manganese is present, solution heat treatment has little or no effect. Perhaps the best test to determine the amount of manganese necessary to inhibit corrosion in a given alloy under all conditions would be to give each specimen of the series a prolonged solution heat treatment and determine the manganese content at which the alloy still retained its resistance to corrosion.

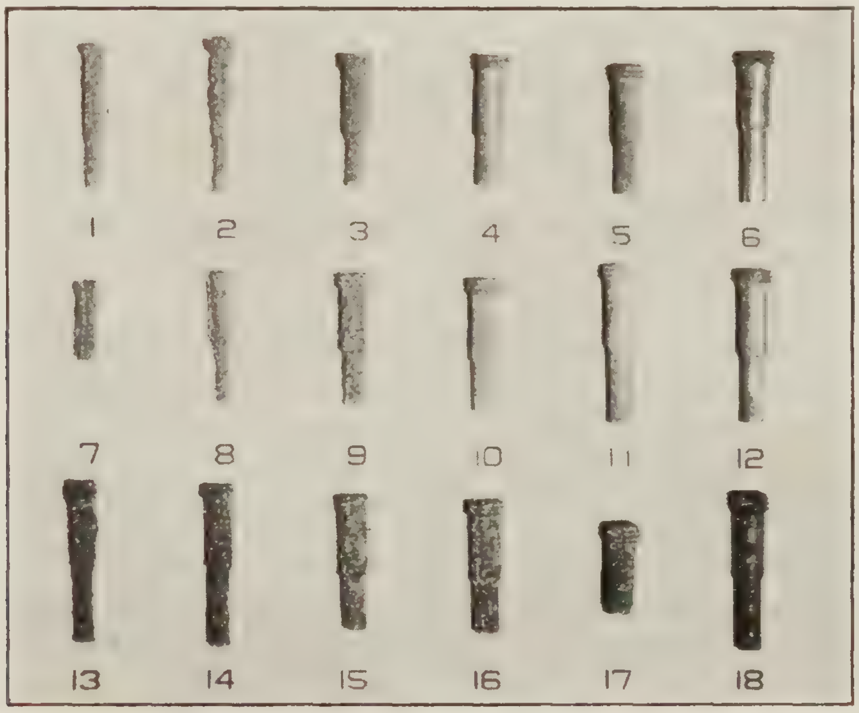


FIG. 35.—Corrosion tests of 12 per cent aluminum alloy containing varying amounts of manganese

Spec. No.	Al	Mn
1	12.05	0.08
2	12.54	.11
3	12.75	.20
4	12.76	.33
5	12.88	.51
6	12.38	.83

Specimens 7, 8, 9, 10, 11, and 12 heat-treated. Specimens 13, 14, 15, 16, 17, and 18 heat-treated and aged

POTENTIOMETRIC INVESTIGATION

Metallographic examination showed the nature of the corrosion attack with the aluminum alloys, and that the increased corrosive action due to added aluminum was not caused by undissolved aluminum constituent. However, it did not show the mechanism whereby aluminum accelerated corrosion, or the function of manganese in counteracting the effect of the aluminum added.

The tendency of magnesium to corrode rapidly is due to its position in the electromotive series. It has been previously emphasized that the corrosion of magnesium in salt solutions is essentially a displacement of hydrogen, and unless the accelerated corrosion of the magnesium-aluminum alloys is caused by a galvanic couple between the magnesium and the undissolved constituents present, any influence which inhibits corrosion must tend either to hinder the magnesium from passing into the solution, or to make it more difficult for the hydrogen to plate out. Granting this assumption, it should be possible to summarize all the ways in which manganese could inhibit corrosion, and to seek experimental evidence from potential measurements to prove the nature of the inhibitive action. The possible effects of manganese may be summarized as follows:

Lowering of the solution tendency of magnesium by:

(1) Mechanical resistance due to a more protective insulating film.
(2) Lowering the solution potential through solid solubility of the manganese.
(3) Lowering the solution potential by the formation of a more protective but not necessarily insulating film.

Hinderance of the plating out of hydrogen by:

(1) Raising the overvoltage of the metal.
(2) Increasing the solid solubility of impurities of low overvoltage from which hydrogen could be easily liberated.
(3) Changing the overvoltage of undissolved constituents.

It was therefore proposed to investigate the following factors by means of potential measurements:

(1) Effect of alloying elements on solution potential.
(2) Effect of the protective film on solution potential.
(3) Nature of galvanic action.
(4) Effect on overvoltage of alloying with aluminum and manganese.

The term "solution potential" will be used to denote the single potential of magnesium in salt solutions rather than the potential of the metal immersed in a normal solution of its ions. The magnesium electrode is highly irreversible and the magnesium ion concentration in the solution has little effect on the value of the potential as measured.

It was not expected that the potential measurements during the process of corrosion could be duplicated to within more than a millivolt, so that extreme precautions for accuracy and the use of an expensive potentiometer and sensitive galvanometer did not seem warranted. The instrument used was the Leeds-Northrup student potentiometer, with a range of 2.2 volts, accurate to 0.5 millivolt. A portable d'Arsonval galvanometer was used, and the sensitiveness was found to be ample. The battery current was controlled by a four-dial Leeds-Northrup resistence box, variable in steps of 1 ohm. The potentiometer circuit was standardized against an Eppley standard cell.

The calomel electrode was of the Fales type, and both normal and tenth normal potassium chloride solutions were used. The calomel was electrolytic, specially prepared for calomel electrodes by the LaMotte Chemical Products Co. An intermediate liquid junction of normal potassium chloride solution was used between the calomel electrode and the corroding medium.

THE SOLUTION POTENTIAL OF PURE MAGNESIUM

The true solution potential of magnesium is difficult to measure, and the cause is usually attributed to the formation of an oxide or hydroxide film. In determining the true potential an amalgam is used, and the values are considerably higher than those obtained by measuring the potential of the metal itself against aqueous solutions. The most accurate determination of the true potential is probably that given by Beck (Reference 1) who obtained a value of -1.856 to -1.876 volts in neutral or acid solutions of $MgSO_4$, in comparison with the normal hydrogen electrode. If the potential is compared with the normal calomel electrode used in the experiments of this section, the true potential would be between -2.14 and -2.16 volts.

In the study of corrosion the true solution potential is of little practical importance, except that the great departure from the true value under corrosion conditions may give some indication of film formation. As rapid corrosion is due to the displacement and liberation of hydrogen, the important value is the *effective* potential, or that available under the actual conditions of corrosion to bring about the displacement of hydrogen.

The single electrode potential of pure magnesium was measured in salt solutions and was found to vary from -1.65 to -1.75 volts in comparison with the normal calomel electrode, depending on the time of immersion and the condition of the surface. The theoretical potential necessary to liberate hydrogen from a solution saturated with magnesium hydroxide is approximately −1 volt on the same scale, so that the solution potential of magnesium greatly exceeds the theoretical potential necessary to plate out hydrogen, even when the solution is alkaline.

THE SOLUTION POTENTIAL OF THE ALUMINUM ALLOYS

It was assumed that aluminum owing to its solid solubility would reduce the solution potential of pure magnesium. To determine quantitatively the effect of potential of the addition of aluminum the series of alloys used in a previous corrosion test (p. 5) was employed. The extruded specimens were annealed at 400° C. for four days and quenched so as to assure a homogeneous structure. The pieces were subsequently machined to a considerable depth to remove surface oxidation, and were rubbed with No. 0 Hubert emery paper to obtain a fresh surface. The specimens were then cleaned with a dry cloth and immersed in a 2 per cent sodium chloride solution. Readings were taken immediately; also the maximum value obtained during immersion in the salt solution was recorded.

SOLUTION POTENTIAL OF THE ALUMINUM ALLOYS

Alloy	Solution potential		
	Immediately after immersion	Maximum	Lowering due to aluminum
Pure metal	1.700	1.705	
Per cent Al.			*Millivolts*
2	1.640	1.648	60
3	1.619	1.619	81
4	1.617	1.617	83
5	1.614	1.615	86
6	1.605	1.611	94
8	1.601	1.624	99

EFFECT OF SMALL AMOUNTS OF MANGANESE ON SOLUTION POTENTIAL

The small amount of manganese necessary to inhibit the corrosion of the aluminum alloys was found to have a negligible effect on solution potential. Specimens of the 4 per cent aluminum alloy, both with and without manganese, showed single potentials indentical to within 1 or 2 millivolts. Hence the inhibiting effect of magnanese could not be attributed to a lowering of solution potential. The aluminum present in the alloys lowered the solution potential to a much greater extent than would be possible with a comparatively small amount of manganese, and any counteracting effect of manganese in lowering the potential by approximately another millivolt would be negligible. A small variation in the aluminum content would cause as great or even greater difference in potential than could be produced by the addition of manganese.

NATURE OF THE PROTECTIVE FILM

It was planned at first to make a series of accurate resistance measurements with the films formed on various alloys to compare their degree of protectiveness, but these experiments have not been completed. Rough measurements have shown that the film formed on pure metal and the resistant alloys has a comparatively low electrical resistance, at least in the early stages of corrosion.

When a reactive metal becomes covered with an adherent film of corrosion product, so that it is protected from further corrosion, the effect is made evident in the measurement of solution potential. Thus aluminum is above zinc in the electromotive series, but when the solution potentials of the two metals are measured in salt solutions the potential of aluminum is usually lower than that of zinc by several tenths of a volt. The aluminum is made "passive" by the presence of the protective film. The active surface of iron is also anodic to the surface of the same metal covered with an oxide film. The phenomenon is quite general, and the low value obtained for the solution potential of magnesium compared with the true potential is probably due to a similar cause, although here the liberation of hydrogen adds another complicating factor.

If the corrosion resistance of the magnesium-aluminum alloys containing manganese were due entirely to the formation of a protective film, the solution potential should be lowered to a greater extent than with the alloys containing only aluminum. After corrosion had proceeded for some time the alloys without manganese should be anodic to the more resistant alloys, owing to the former presenting an active surface. Potential measurements showed that in every case the reverse was true. The manganese alloys were always anodic to the aluminum alloys containing no manganese. As the corrosion product accumulated on the alloy which was rapidly corroding, the solution potential dropped off correspondingly, but the potential of the resistant alloys still retained its high value.

The effect of film on the solution potential of pure metal was also measured over a period of two weeks' immersion. The values of the single potential with respect to the normal calomel electrode are given in the following table:

EFFECT OF FILM ON THE POTENTIAL OF PURE MAGNESIUM

Time after immersion	Potential	
Instantaneous reading	1.700	Rapid evolution of hydrogen
1 minute	1.703	
5 minutes	1.705	
15 minutes	1.704	
30 minutes	1.700	
1 hour	1.697	
2 hours	1.687	
4 hours	1.687	Slight evolution of hydrogen
8 hours	1.683	
24 hours	1.675	
2 days	1.670	
1 week	1.668	
2 weeks	1.663	

Although all visible hydrogen evolution ceased after the first day, the potential was still much higher than that theoretically necessary to plate out hydrogen as a gas, namely, -1 volt. This could mean only one of two things: Either the film was sufficiently insulating to stop chemical action and the high potential was exerted merely through a few pores of high electrical resistance, or else the film had lowered the solution potential to the point where it no longer exceeded the theoretical hydrogen potential plus the overvoltage of the metal. Experiments were undertaken to determine which of these conditions obtained.

Two machined electrodes from the same piece of magnesium ingot were immersed in 2 per cent salt solutuion until covered by the protective film. After about 26 hours all visible evolution of hydrogen had ceased, and the potentials were the same to within a millivolt. An external E. M. F. of 0.2 volt was applied across the two electrodes; when the circuit was closed hydrogen was immediately liberated from the magnesium cathode, even though covered with the film which stopped further action in salt solution. Since the total E. M. F. applied was only 0.2 volt, the depression of the cathode potential below that which it normally had before application of the current was less than this, and probably less than a tenth of a volt. Hence by merely depressing the potential from the original value of -1.70 to that of -1.80 volts (making it "higher" in a negative sense) vigorous evolution of hydrogen resulted. The potential was already 0.7 volt higher than the theoretical value necessary to displace hydrogen, and yet no hydrogen was liberated until the additional tenth of a volt was applied. When the circuit was broken and the additional potential removed, the evolution of hydrogen ceased.

This leads to the assumption that the film reduces the solution potential to a critical value where it is no longer able to displace hydrogen. If so, the overvoltage of magnesium must be comparatively high.

Another evidence that the corroded specimen is able to function as cathode in spite of the protective film is shown by the current generated when it is merely connected to a piece of the same metal having a clean surface. Here the differences in potential are small, but a current of from 2 to 3 milliamperes may be obtained. The amount of hydrogen liberated cathodically is negligible compared with that liberated from the fresh piece, but this is to be expected because of the small difference in potential and the high electrical resistance of the cell.

If the overvoltage of magnesium is high and the film is not protective in the sense that it is insulating, then hydrogen should be readily liberated by merely connecting with a metal of low overvoltage.

An electrode made from magnesium ingot was allowed to stand in 10 per cent salt solution for a week to assure the protective nature of the film, and all signs of hydrogen liberation had apparently ceased. The electrode was then connected to a platinum rod immersed in the same beaker. Hydrogen was liberated vigorously from the platinum, and a current of from 30 to 40 milliamperes was obtained. Thus the film was not protective in preventing anodic action when an area of low overvoltage was exposed for the liberation of hydrogen.

The preceding experiments show that magnesium when covered by a protective film can function either cathodically (liberating hydrogen) or anodically (passing into solution) when potential or overvoltage relations are altered. That the corrosion of the magnesium when in contact with platinum was due to the low overvoltage of the platinum and not to the difference in potential between the two metals owing to their position in the electromotive series will be proved in the following section.

The older ideas of corrosion involved the formation of a galvanic couple between the more reactive metal and noble impurities, and the driving force of corrosive action was supposedly the difference in potential between the two metals, which in turn depended on their position on the electromotive series. According to this view resistance to corrosion implied homogeneity; alloys possessing a heterogeneous structure and having phases or parts differing in solution potential from the remainder should function as galvanic cells, at least in the case when hydrogen is liberated. The following experiments show that galvanic action depends on overvoltage rather than a difference in solution potential between the two metals.

It has been emphasized that corrosion is essentially a displacement of hydrogen. If the solution potential of the metal is higher than the theoretical potential necessary to liberate hydrogen plus the overvoltage of the metal, hydrogen will be liberated on the surface of the metal irrespective of the presence of impurities. When this condition obtains with magnesium, an external connection to a piece of copper immersed in the same solution only slightly accelerates corrosion. The greater part of the hydrogen is still liberated from the magnesium surface, even in the case of very pure metal.

When the overvoltage is high and the solution potential is not sufficiently great to displace hydrogen on the surface of the metal, then the total hydrogen displacement will take place from such impurities of low overvoltage as the metal may happen to contain. If the impurities have an overvoltage as high or higher than that of the metal itself, then hydrogen can not be displaced as a gas no matter what difference in solution potential exists between the reactive metal and the impurity. As the cell is short circuited the magnesium merely imparts its high solution potential to the impurity; if the overvoltage of the impurity is low enough so that hydrogen can be liberated at this high potential, then gaseous evolution will take place and current will flow; if not, current will only flow momentarily until the electrode polarizes and acquires the same potential with respect to the solution as the surrounding magnesium, whereupon action will cease.

An experiment was made to quantitatively verify these assumptions. Platinum and mercury, which are close together in the electromotive series but differ greatly in overvoltage, were chosen as cathodes of a short-circuited corrosion cell which was set up as shown in Figure 36. A magnesium electrode was used as anode; the electrode had been previously immersed in 10 per cent salt solution for several days and all visible signs of hydrogen evolution had ceased. The metal was covered by the so-called protective film.

The overvoltage of mercury is higher than that of any other metal which has as yet been measured, while the overvoltage of platinum is known to be low. Hence, unless the protective film in the magnesium were insulating and prevented anodic action, we should expect a current to flow and the magnesium to dissolve when connected to platinum; on the other hand, only a momentary current should be produced with mercury, and the magnesium anode should remain unattacked, even though there is a difference in potential between the two metals of nearly two volts when measured on open circuit.

The differences in potential between magnesium and the two cathode metals were measured on open circuit with the potentiometer and were found to be almost identical:

	Volts
Magnesium-platinum	1. 62
Magnesium-mercury	1. 64

The latter potential dropped to 1.59 volts merely due to polarization by the small current which flowed through the galvanometer.

When the cells were short-circuited through a milliammeter the one having a mercury cathode gave only a momentary current which soon dropped to zero. The platinum cell was still giving quite a high current after 48 hours when the experiment was discontinued.

Time	Current	
	Mercury	Platinum
	Milliamperes	*Milliamperes*
Initial current	4	6
1 minute	2	25
2 minutes	1	30
5 minutes	0. 5	30
10 minutes	.3	30
30 minutes	.3	34
2 hours		40
24 hours		40
48 hours		31

The platinum cathode was only a one-eighth inch rod and furnished much less area than the mercury, but after 10 minutes it produced nearly 90 times the current which flowed when mercury was used as cathode. The cell was carefully tested for external resistance, particularly with respect to the mercury column used for connection to the mercury cathode. When this column was introduced into the circuit while the magnesium was connected to the platinum no change in current resulted.

There was no evidence of hydrogen evolution from the mercury, but hydrogen was evolved vigorously from the platinum. At the end of 48 hours the electrode connected to the platinum was badly corroded and reduced to about two-thirds its original size, while the electrode connected to the mercury was unattacked except for the small amount of pitting due to the normal action of salt water. The two electrodes together with a reference electrode which had been immersed merely in the same depth of salt solution for the same length of time are shown in Figure 36.

The experiment showed that polarization is the controlling factor in galvanic action rather than difference in solution potential. This, in turn, depends almost entirely on overvoltage. The mechanism of the action may be pictured as follows:

The electrolytic corrosion cell is short circuited and there is practically no drop in potential through the metal. Thus the second metal or impurity tends to assume practically the same high potential as the magnesium. However, if the overvoltage is low, it can not keep this potential with respect to the solution, for hydrogen will plate out before the potential can be built up to this value. The impurity then functions not as a metal electrode but as a hydrogen electrode. If the impurity has no overvoltage it assumes practically the true hydrogen potential. If it has approximately two-tenths volt overvoltage it will assume a potential two-tenths volt higher than this. If the overvoltage equals or is greater than that of the reactive metal no current will flow unless the potential of the reactive metal is high enough to displace hydrogen on its own surface. Under any condition there is only a few tenths of a volt difference in *effective* potential between magnesium and the impurity. This effective potential difference may even be zero, whereas the difference in potential on open circuit may be from one to two volts.

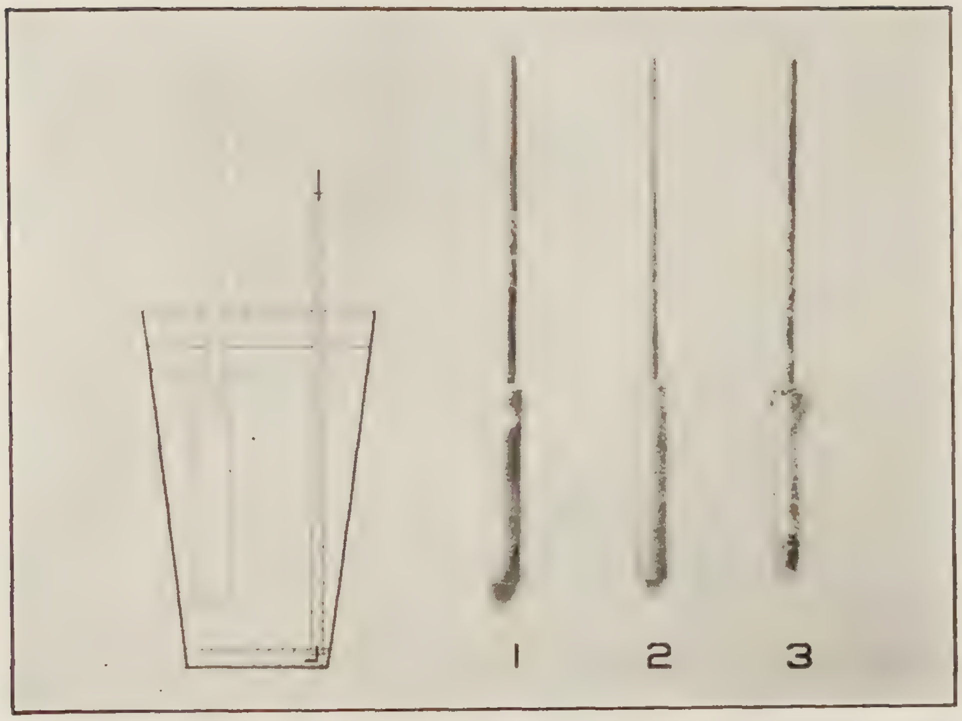


FIG. 36.—Electrolytic cell and electrodes used in overvoltage experiment. (1) Immersed in 10 per cent NaCl solution 7 days. (2) Connected to mercury 48 hours. (3) Connected to platinum 48 hours

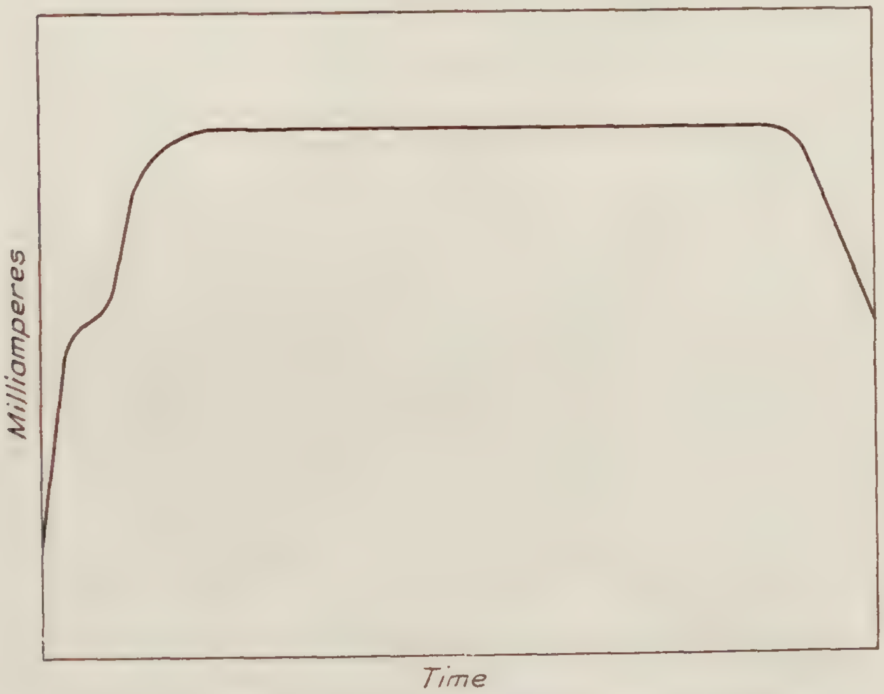


FIG. 37.—Current. Time curve for electrode connected to platinum

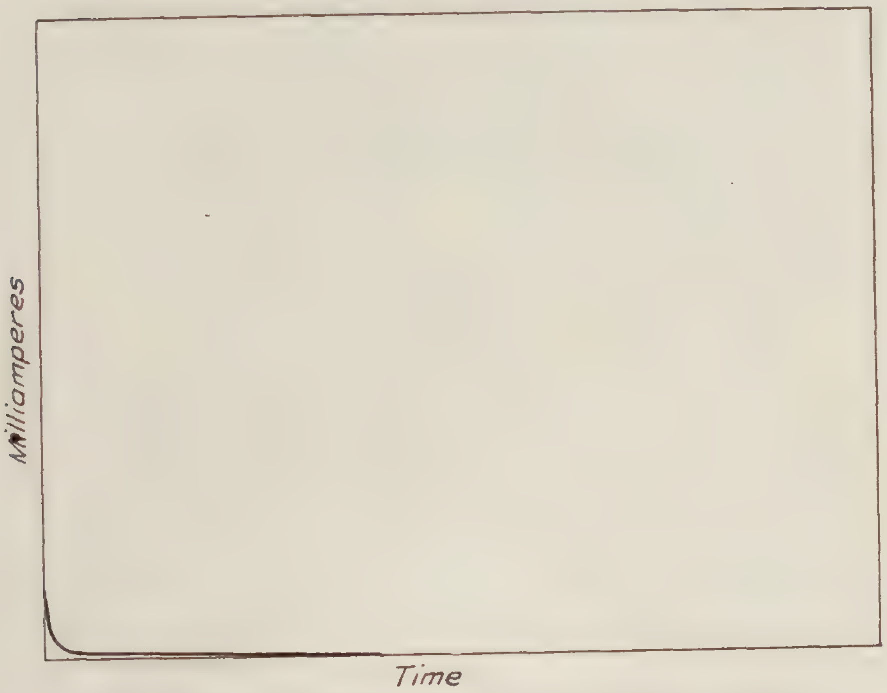


FIG. 38.—Current. Time curve for electrode connected to mercury

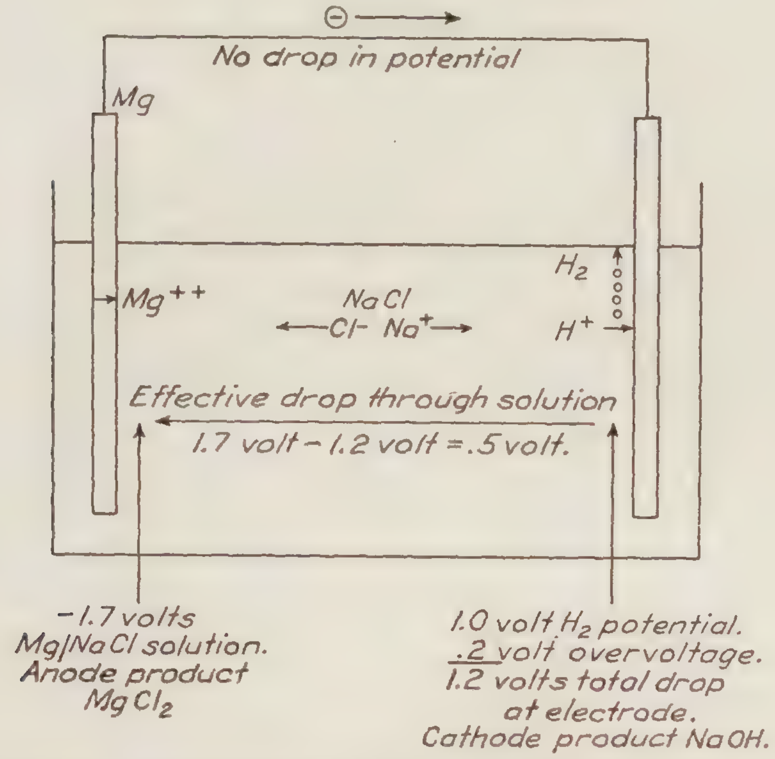


FIG. 39.—Diagrammatic representation of galvanic action with impurity of low overvoltage

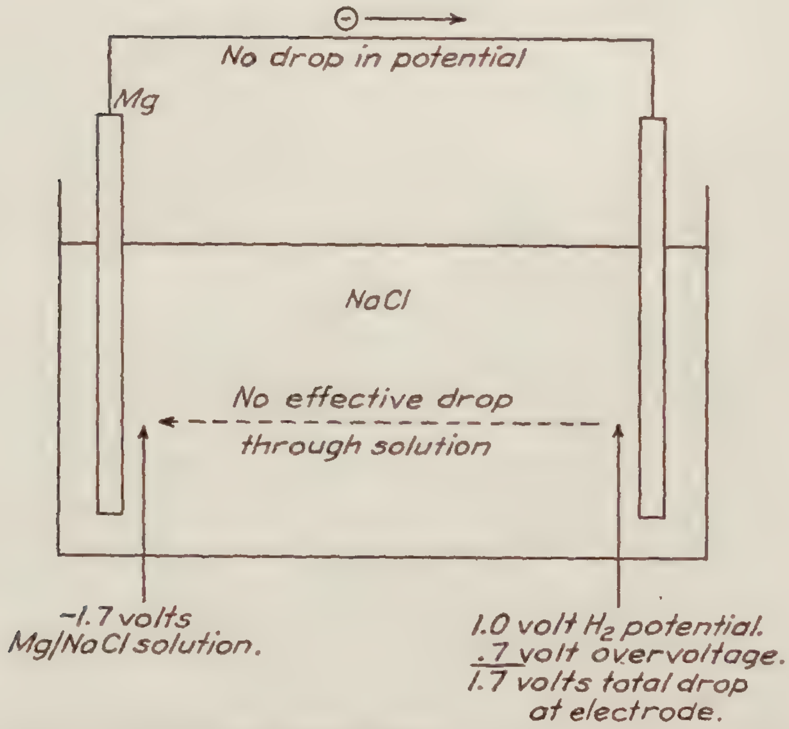


FIG. 40.—Diagrammatic representation of galvanic action with impurity of high overvoltage

ACTIVATION OF THE PROTECTIVE FILM THROUGH THE FORMATION OF A GALVANIC COUPLE

In the experiments on galvanic action in which magnesium was connected to platinum it was noted that some hydrogen came from the magnesium as well as from the platinum rod acting as cathode. All liberation of hydrogen from the corrosion specimen had ceased before the two metals were connected so that there was evidently some activation of the film by electrolysis.

In subsequent experiments using other metals than platinum an effort was made to decrease the resistance of the electrolytic cell by employing larger cathodes, and it was found that immediately on short circuiting these cells hydrogen was liberated vigorously from the magnesium anode as well as from the cathode. In some cases it seemed that more hydrogen was liberated from the magnesium than from the second metal employed in the galvanic couple. When the circuit was broken the rate of hydrogen evolution from the magnesium decreased rapidly and finally became inappreciable, but when the circuit was again closed the evolution of hydrogen immediately became vigorous. The phenomenon could apparently be repeated as often as desired.

These observations showed the presence of an unusual condition which is not present in the corrosion of less reactive metals. Although corrosion may be caused entirely by the electric current which is set up when magnesium is connected to an impurity of low overvoltage, the actual current which flows may account only for a small portion of the metal which dissolves. The film of corrosion product which would protect the anode unless current were passing is activated so that additional metal is dissolved owing to a displacement of hydrogen directly on the magnesium surface.

If the liberation of hydrogen were due to an activation of the protective film, this should make itself evident on measuring the solution potential immediately after the circuit is broken. Potential measurements showed a rise in potential of approximately 10 millivolts which dropped rapidly to the normal value, whereupon the liberation of hydrogen practically ceased.

In all electrolytic corrosion in chloride solutions where the anode and cathode are separated by an appreciable distance, the primary corrosion product is magnesium chloride and not magnesium hydroxide. Previous investigators have shown that magnesium chloride is more corrosive in its action toward magnesium than either sodium or potassium chlorides; Evans (Reference 2) has maintained that the peptization of the hydroxide film by alkali chlorides is due to the magnesium chloride formed during corrosion.

In addition to peptization, or the tendency of the magnesium chloride to cause the hydroxide film to pass into colloidal solution, there are a number of possible reasons for the activation of the film by electrolysis. One factor which may be of importance and which has never before been mentioned is the "acid effect" exerted by magnesium chloride. A saturated solution of magnesium hydroxide is slightly less alkaline when a large amount of magnesium chloride is present, as may be shown by electrometric titration curves.

When the hydrogen ion concentration is increased even slightly, the potential necessary to plate out hydrogen is lowered. Since the film on the magnesium is not insulating and the solution potential of the metal is now higher than the sum of the hydrogen potential plus the metal overvoltage, hydrogen will be displaced.

It has been shown by the work of Evans (Reference 3) and others that the pitting of iron and steel is due almost entirely to differential aeration, or unequal access of oxygen to different parts of the specimen. Evans succeeded in measuring the current between aerated and unaerated pieces of iron, and found that it accounted for nearly 80 per cent of the total corrosion. The corrosion of magnesium is entirely different in type but it semed of interest to determine the effect of atmospheric oxygen on solution potential.

Two electrodes of pure metal were immersed in the same beaker and allowed to corrode until there was no visible liberation of hydrogen. The pieces were connected to a galvanometer; one of the pieces was removed from the solution for a moment and then immersed again in the salt solution. A current was indicated on the galvanometer. The other electrode was then removed and reimmersed, and a current flowed in the opposite direction. Thus the aeration currents of Evans were detected, even when the magnesium was covered by a protective film.

Solution potentials were then measured, using the magnesium electrode in comparison with the normal calomel electrode. After aeration the potential dropped 5 to 10 millivolts, but on standing in the salt solution it soon returned to its normal value. This drop in potential due to aeration was observed even with pieces which had been previously immersed in salt water for a period of six weeks.

NATURE OF PITTING

Although it was believed that pitting of magnesium was due principally to surface condition and to factors external to the structure of the metal, it was at first very difficult to formulate a theory whereby the phenomena observed in localized corrosion could be satisfactorily explained. In the first place, hydrogen usually came from the pit. As the pit penetrated more deeply into the metal hydrogen continued to come from the bottom of the pit, even when the depth had advanced a measurable distance from the point of inception. This in itself made it difficult to believe that the action was due to an undissolved impurity, unless the entire area in the direction of pitting contained this impurity, for the seat of hydrogen liberation changed with advancing depth. Microscopic examination showed no segregation of impurities in the pitted areas to account for the facts observed.

The investigation with the potentiometer as outlined up to this point furnishes an explanation of pitting which is believed to be essentially correct.

When magnesium is immersed in a salt solution practically the entire outer surface is eaten away. During the formation of the film of corrosion product there are bound to be irregularities. Anode and cathode areas will consequently be set up. Even immediately on immersion these differential areas will be established owing to surface irregularities and oxidation films of varying thickness.

It has been shown that a measurable current could be obtained by merely connecting a piece of magnesium covered with a protective film to a clean electrode made from the same metal. In the overvoltage experiments it was found that electrolysis activated the film on the anode area, raised the solution potential, caused the liberation of hydrogen from the anode, and kept a protective film from forming as long as the current passed. At the bottom of a corrosion pit we have such a set of conditions. The film of flocculent precipitate protects the anodic area inside the pit from the action of oxygen which would tend to lower the solution potential. The entire piece may function as cathode, both through the liberation of hydrogen and through depolarization with atmospheric oxygen. The anode is centered on one point or at the most a small area at the bottom of the pit. The magnesium chloride content of the pit becomes high through electrolysis; this has a great activating tendency, probably both through peptization of the hydroxide film and through some slight change in hydrogen ion concentration. Hydrogen is liberated from this active surface within the pit, and the process is continuous. Metal dissolves both through electrolysis and by a direct displacement of hydrogen from the active surface, and the actual current flowing may account for only a small part of the metal dissolved.

This theory as outlined explains why pitting is continuous when once started and why hydrogen comes from the bottom of the pit. Cases have been observed where a pit has started from one side of the piece and eaten entirely through it, so that the specimen could be broken in two with little effort. The presence of impurities of low overvoltage is not necessary for pitting, for experiment has shown that the piece itself can act as a cathode even when covered with a protective film. The important point is that in corrosion by electrolysis the primary product of corrosion is magnesium chloride and not hydroxide. The activating effect of the magnesium chloride probably accounts for the extreme depth of the pits in comparison with the corrosion of the surrounding metal and the fact that pitting when once started is continuous.

The presence of impurities of low overvoltage will probably cause pitting if these impurities are segregated, but this is seldom the case. In the copper alloys where the constituent is evenly distributed the attack, although rapid, is general over the surface, and the entire piece disintegrates without the formation of deep pits. If the overvoltage of the impurity is as high or higher than that of magnesium, the impurity will have little effect on either general or localized corrosion.

PROBABLE ACTION OF MANGANESE IN PREVENTING CORROSION

Although the experimental work of the corrosion investigation has not been carried to a point where conclusions can be drawn with certainty, the experimental facts seem to point to one explanation for the inhibiting action of manganese on the corrosion of the mangesium alloys containing aluminum. The explanation may be summarized as follows:

The overvoltage of pure magnesium is quite high. On immersion in salt water the metal corrodes with the liberation of hydrogen until the film of corrosion product lowers the potential to a critical value. When the potential reaches this value it no longer exceeds the theoretical hydrogen potential plus the overvoltage of the metal. Rapid corrosion consequently ceases. When aluminum is added, especially when in large amounts, the overvoltage is decreased and hydrogen plates out at a much lower potential than with pure magnesium. The addition of a small amount of manganese raises the overvoltage back to practically that of pure metal, and the film is again protective.

It is not maintained that the interfering action of the film due to mechanical resistance is negligible, as this factor is probably of considerable importance. The experimental evidence merely indicates that it is not sufficient in itself to stop corrosion at the point where visible action ceases. As long as potential and overvoltage relations are favorable for the liberation of hydrogen, corrosion will continue until the piece is disintegrated.

CONCLUSIONS

1. Pure magnesium of ordinary ingot grade is quite resistant to corrosion by salt water.
2. The addition of aluminum increases the rate of corrosion, but the presence of a small amount of manganese counteracts to a large extent the effect of the added aluminum.
3. No relation can be traced between the presence of undissolved constituents and the rate of corrosion of the magnesium-aluminum alloys.
4. There is a definite relation between cored structure and corrosion. The magnesium-rich dendrites are eaten out as if by direct attack.
5. Coring is not the cause of corrosion but is merely responsible for the dendritic nature of the attack.
6. Magnesium silicide is inactive during corrosion.
7. The aluminum constituent, at least when present in small amounts, is inactive.
8. Nonmetallic inclusions are inactive during the initial corrosion attack, but the inclusions may act as nuclei for the crystallization of the magnesium-rich dendrites. The latter are attacked by salt water and give the appearance in the corroded specimen of a relation between inclusions and corrosion.
9. A critical amount of manganese is necessary to inhibit the corrosion of the magnesium-aluminum alloys. The amount increases with the quantity of aluminum in solid solution. At least three-tenths per cent manganese should be present in the 4 per cent aluminum alloy.
10. Alloys which do not contain the critical amount of manganese corrode until completely disintegrated.
11. An excess of manganese over the critical amount slightly decreases the resistance to corrosion but does very little harm. It is better to have too much than too little manganese present.
12. Heat treatment of the aluminum alloys containing too little manganese makes them much less resistant to corrosion. If sufficient manganese is present, heat treatment has practically no effect.
13. The protective film formed on resistant corrosion specimens does not stop electrochemical action by actual insulation. A change in potential relations of less than one-tenth volt will cause the liberation of hydrogen.

14. The electrical resistance of the film is small and is of the order of magnitude of a few ohms.

15. When a specimen covered by a protective film is connected to a metal of low overvoltage the magnesium corrodes rapidly and the film is activated so that hydrogen comes from both the magnesium anode and the metal acting as cathode.

16. Overvoltage of impurities and not their position in the electromotive series is the factor which determines whether they are active or inactive during corrosion.

17. Pitting is probably due to the activation of the film on the anodic areas by the formation of magnesium chloride during electrolysis. As long as current flows the action will be continuous.

18. Aluminum apparently lowers the overvoltage of magnesium. Hydrogen is liberated at a much lower potential during corrosion than is the case with pure magnesium.

It is concluded that manganese raises the overvoltage of the aluminum alloys back to practically that of pure magnesium.

REFERENCES

1. Beck, R. P. ---------- Rec. Trav. Chem. *41* (1922), 353.
2. Evans, U. R. ---------- Trans. Faraday Soc. *28* (1922), 1.
3. Evans, U. R. ---------- J. Inst. Met. *30* (1923), 257.

REPORT No. 249

A COMPARISON OF THE TAKE-OFF AND LANDING CHARACTERISTICS OF A NUMBER OF SERVICE AIRPLANES

By THOMAS CARROLL
Langley Memorial Aeronautical Laboratory

REPORT No. 249

A COMPARISON OF THE TAKE-OFF AND LANDING CHARACTERISTICS OF A NUMBER OF SERVICE AIRPLANES

By Thomas Carroll

SUMMARY

This investigation, which is a continuation of Technical Report No. 154, "A Study of Taking Off and Landing an Airplane" (Reference 1), follows very closely the earlier methods and covers a number of service airplanes, whereas the previous report covered but one, the JN–4h.

In addition to the air speed, acceleration, and control positions as given in Report No. 154, information is here given regarding the distance run and the ground speed for the various airplanes during the two maneuvers.

INTRODUCTION

It was stated in Technical Report No. 154 that little attention had been given to taking off or landing. While the performance of the airplane as to speed, climb, ceiling, and to a certain extent also as to controllability, maneuverability, and stability, is subject to a quantitative analysis, the maneuver of taking off or landing is difficult to evaluate, because it is dependent upon the pilot's ability, the power plant, and weather and field conditions. Variations arising from differences in the skill of the pilot are not considered in this report, and an attempt has been made to reduce all of the maneuvers to average landings or take-offs.

Complete records of a number of flights were obtained on each of the airplanes investigated, and only records of good average grade, free from extraneous influences, were selected for consideration. The results are given in one form in Table I to show the relation of the various factors which enter into the maneuver for each airplane, and again in Tables II and III in forms from which comparisons may readily be made among the different types investigated.

The procedure followed was identical with that described in Technical Report No. 154, with the addition of evaluations of the ground speeds and distances of ground run. Each of the landings was made from a straight glide directly into the wind, using the best available portion of the landing field. The throttle was tightly closed and the idling adjustment was normally slow. In the take-off the throttle was opened fully in the shortest possible time commensurate with good practice, and the take-offs were accomplished in a modified tail-high position. This is at variance with the practice of a prolonged maintenance of the tail-high position recommended in Report No. 154, and was made necessary by the poor condition of the landing field at Langley during the time these tests were in progress. However, such a modified take-off is considered to be in accordance with average practice.

AIRPLANES INVESTIGATED

Curtiss JN–6h.
Vought VE–7.
DH–4b.
Fokker CO–4.
SE–5a.
SPAD–VII.
Thomas-Morse MB–3.
Martin Bomber MB–2.
Sperry Messenger.

Several pilots assisted in securing the data of this report, but all the flights recorded were made by the pilots of the committee's staff with the exception of those on the Martin Bomber MB-2, which were made by a service bomber pilot. An average of 10 complete records was obtained on each airplane in the two maneuvers under investigation.

INSTRUMENTS AND INSTALLATION

The instruments used were, with one exception, identical with those employed in the earlier work, and were of the recording type as developed at the laboratory of the National Advisory Committee at Langley Field. These instruments comprised the following:

(1) N. A. C. A. control position recorder (Reference 2). This instrument was attached directly to the control cables in the fuselage. Slight errors may be seen in the records, which were due largely to slack in the controls. A precision of plus or minus 10 per cent was obtained.

(2) The N. A. C. A. accelerometer (Reference 3), which measured the acceleration during the maneuvers and also located definitely the instant at which the ground contact was made or broken.

(3) The N. A. C. A. air-speed recorder (Reference 4), equipped with the universal swiveling Pitot head, as developed at the laboratory. This was used for measuring the air speed with an accuracy of plus or minus 3 per cent.

The fourth instrument used was a specially designed and constructed ground-speed recorder which has not been described previously. This recorder consisted of a small air compressor attached to the stationary axle of the chassis and actuated by a plunger which was depressed by an eccentric race or cam attached to the side of the airplane wheel. Each impulse of this compressor was transmitted by a tube to one side of a diaphragm instrument of the usual recording type and represented one revolution of the wheel. Thus the distance of the roll was obtained by multiplying the number of such recorded revolutions by distance obtained by rolling the wheel one revolution under full load and on a flat surface. Many records indicated that the wheel began to turn either slightly before or shortly after impact with the ground. This was accounted for in the first instance by the dragging of the wheel over high grass or weeds, and in the second by a very small slippage over smooth or soft ground. Correction was made by using the accelerometer record as indicating the true point of contact. As a further check several ground runs were measured by chain, and no appreciable error in the records was found. The individual records may be taken as correct within plus or minus 20 feet.

All of the instruments were synchronized through a chronometric timer, which produced a vertical line across the moving film at regular intervals to provide a basis for the correlation of all the records. A single electric switch in the cockpit controlled all the instruments.

RESULTS

The records obtained for each of the airplanes are shown in Figures 1 to 9a. These show the air speed, ground speed, ground-run distance, acceleration, and position of all controls throughout the maneuver, plotted against time.

Table I gives a recapitulation of the results reduced to zero wind speed.

The first inspection of the data may be somewhat confusing, due to the difference between instrumental records and visual impressions, since it usually appears to the casual observer that a large airplane flies and lands very slowly and a small one lands very fast. From casually observing a number of airplanes landing it is difficult for an untrained observer to believe that a Martin Bomber and a Thomas-Morse pursuit airplane land at about the same speed, or that a Martin Bomber lands about 15 miles faster than a Sperry Messenger. Of course the landing speed varies as the square root of the wing loading and inversely as the maximum lift coefficient, but we are now concerned with the impressions obtained by casual observation.

The weights given are the actual weights as measured with the airplane ready for flight. No attempt was made to run at the full military load, but the weights given will indicate the proportion of load which each airplane carried. These weights did, however, include a full crew for each airplane.

Figures 10 and 11 present the method of reducing the data to a condition of zero wind speed by plotting the various ground distances observed against the various wind velocities at the ground at the time the record was taken. Assuming that an airplane landing in a wind of a velocity equal to its landing speed has zero ground run, a fair curve was drawn through the point on the ordinate axis representing the landing speed and the group of observed points. The intersection of this curve with the base line indicates the ground run at zero wind speed. Since the observed points are usually at low wind speeds, the error can not be large. These figures present valuable information as to the ground run which may be expected of any of these various types of airplanes in winds up to and including their landing speeds. The manner of approach should not change the landing speed, which is definite for any airplane with a constant weight. The ground run is dependent on landing speed and wind velocity and is independent of the method of approach.

CONCLUSION

It is hoped that the results presented will prove of value to pilots in considering the ground maneuvers of certain airplanes, particularly in regard to the runway required to take-off or land under various conditions of wind speed; or to others in estimating the proper size for proposed landing fields, etc. It is recommended that further work be done covering those phases of taking off and landing which are not definitely tied up with the performance of the airplane; that is, the effect in approaching a landing in "side-slip," in "fish-tailing," or in making use of the avilable side winds, which permits setting the airplane down in a more confined space. This information in conjunction with the present report and report No. 154 would cover these maneuvers comprehensively.

TABLE I

	Weight, pounds	Wing loading, lb. / sq. ft.	Nominal power loading lb. / HP.	Take-off run, feet	Take-off air speed M. P. H.	Landing run, feet	Landing air speed M. P. H.	Angle of attack of wings on ground, degrees
SE-5a	2,080	8.67	11.5	300	53	450	54	14
JN-6h Curtiss	2,767	7.85	18.5	410	48	575	51	13.2
SPAD-VII	1,625	8.40	9.0	315	58	485	58	15.4
VE-7 Vought	2,152	7.57	12.0	275	50	800	51	12.7
DH-4b	4,000	9.10	10.0	340	51	725	56.5	12.3
CO-4 Fokker	4,155	10.10	10.4	380	52	950	56	11
Sperry Messenger	965	6.5	16.0	320	42	400	44	17.2
MB-3 Thomas-Morse	2,277	9.63	7.6	325	57	875	57	15
MB-2 Martin Bomber	10,520	9.7	13.2	585	63	925	58	13

TABLE II

COMPARATIVE SPEEDS AND DISTANCES OF TAKE-OFFS

	Speed, M.P.H	Distance, feet
1. Sperry Messenger	42	310
2. JN-6h Curtiss	48	390
3. VE-7 Vought	50	275
4. DH-4b	51	340
5. CO-4 Fokker	52	382
6. SE-5a	53	300
7. SPAD-VII	58	315
8. MB-3 Thomas-Morse	58	325
9. MB-2 Martin Bomber	63	550

TABLE III

COMPARATIVE SPEEDS AND DISTANCES IN LANDINGS

	Speed, M. P. H.	Distance, feet
1. Sperry Messenger	44	400
2. JN-6h Curtiss	51	575
3. VE-7 Vought	51	800
4. SE-5a	54	450
5. MB-3 Thomas-Morse	56	875
6. CO-4 Fokker	56	950
7. DH-4b	56. 5	725
8. SPAD-VII	58	485
9. MB-2 Martin Bomber	58	925

REFERENCES

1. Carroll, T. A Study of Taking Off and Landing an Airplane. N. A. C. A. Technical Report No. 154, 1922.

2. Norton, F. H. N. A. C. A. Control Position Recorder. N. A. C. A. Technical Note No. 97, May, 1922.

3. Norton, F. H., and Brown, W. G. The Pressure Distribution Over the Horizontal Tail Surfaces of an Airplane, III, 1922. N. A. C. A. Technical Report No. 148.

4. Norton, F. H. N. A. C. A. Recording Air Speed Meter. N. A. C. A. Technical Note No. 64, October, 1921.

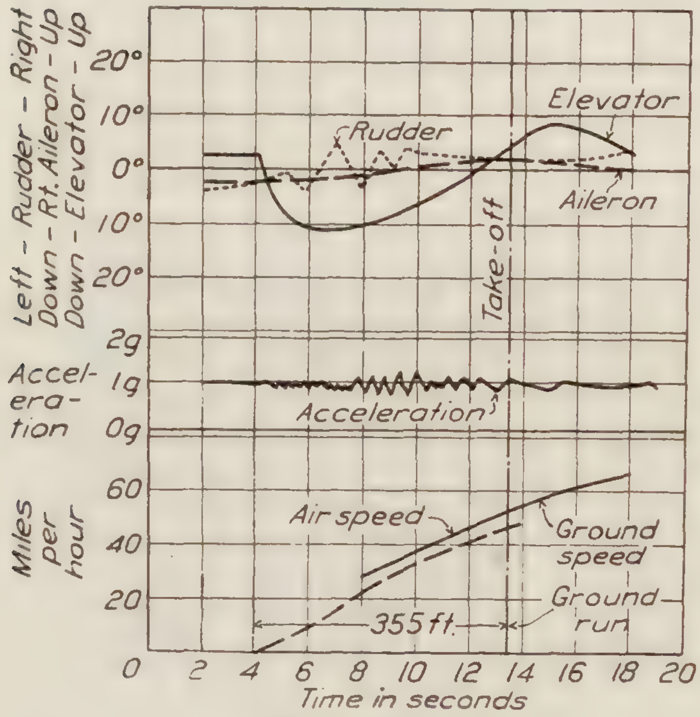


Fig. 1.—Take off. CO-4

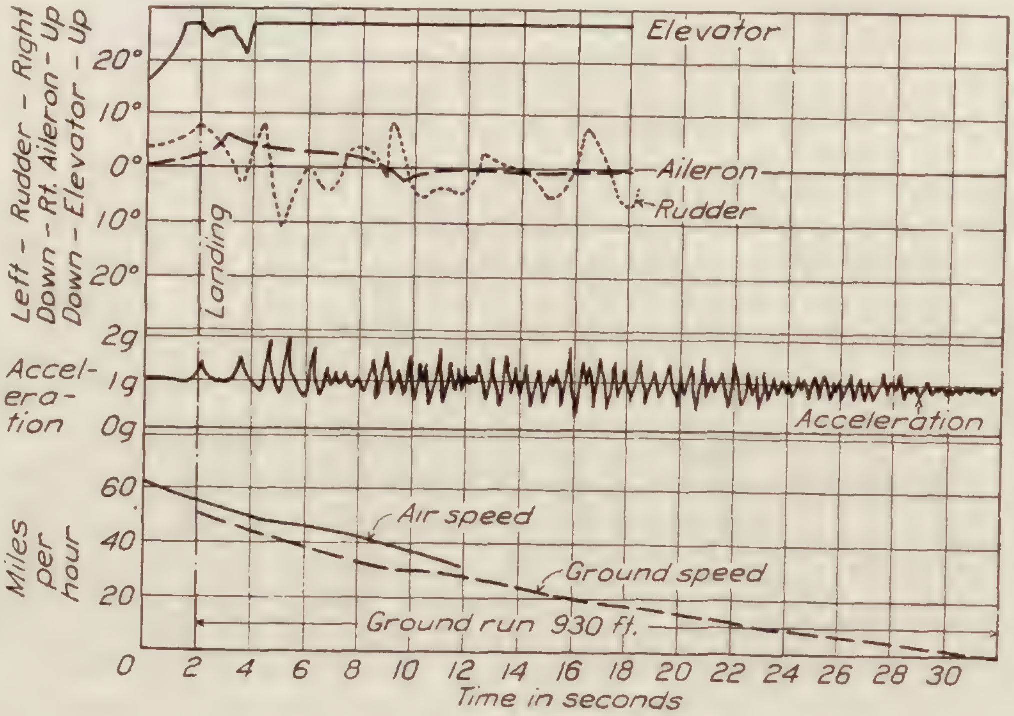


Fig. 1a.—Landing. CO-4

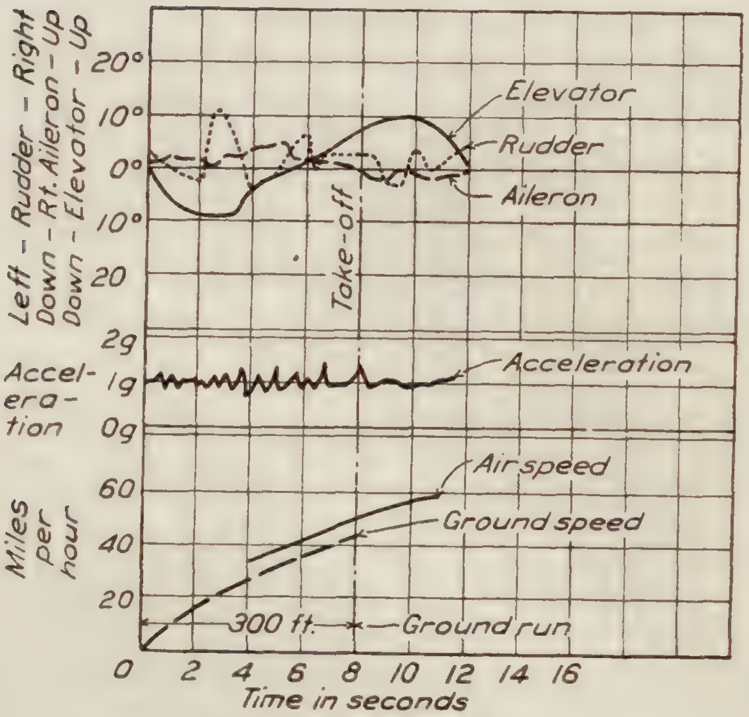


Fig. 2.—Take off. DH-4b

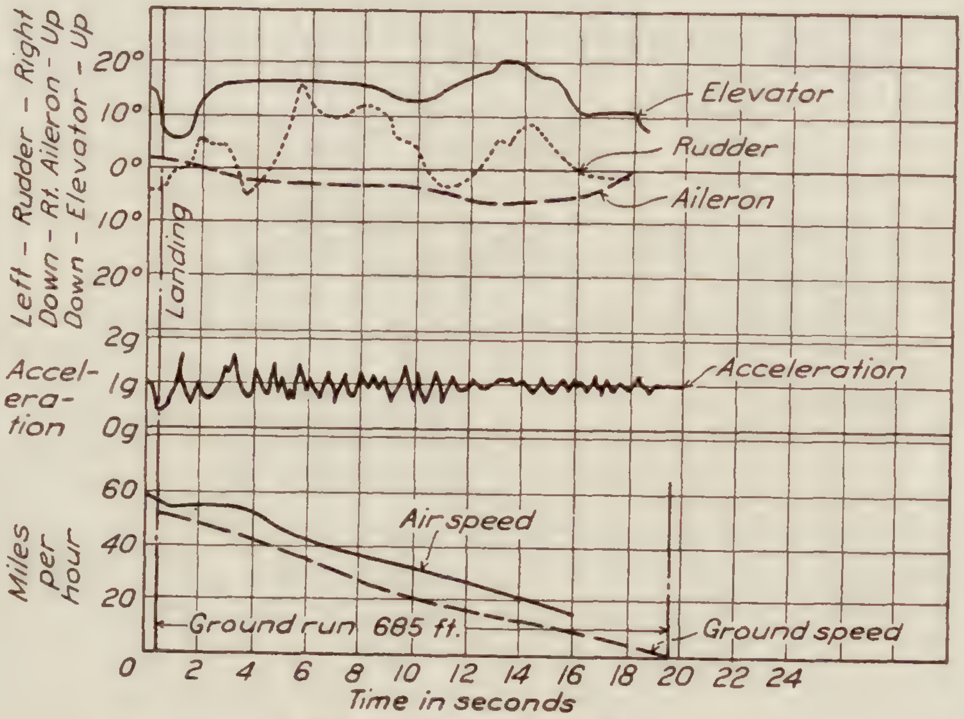


Fig. 2a.—Landing. DH-4b

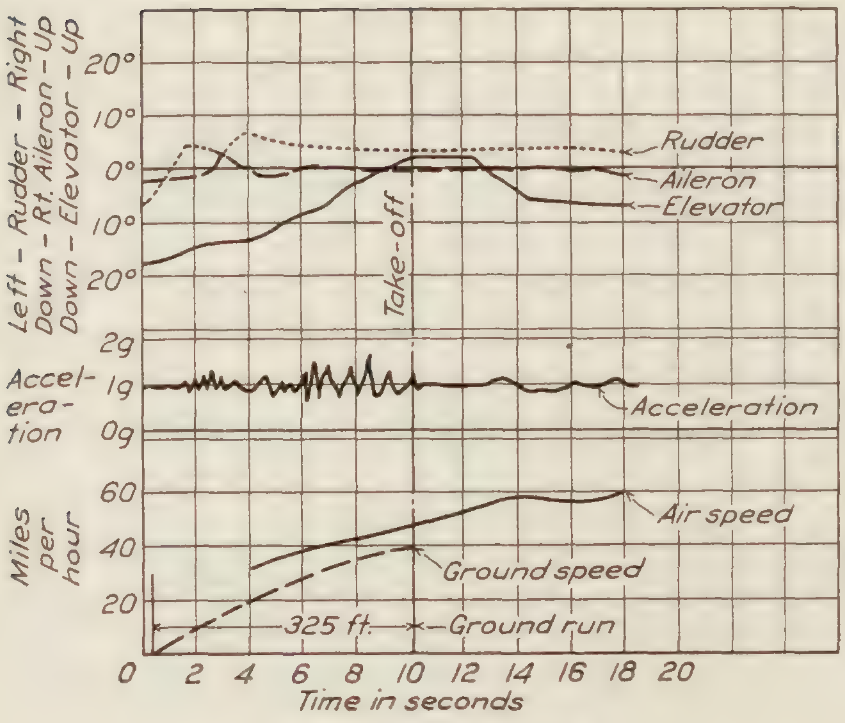


FIG. 3.—Take off. JN-6h

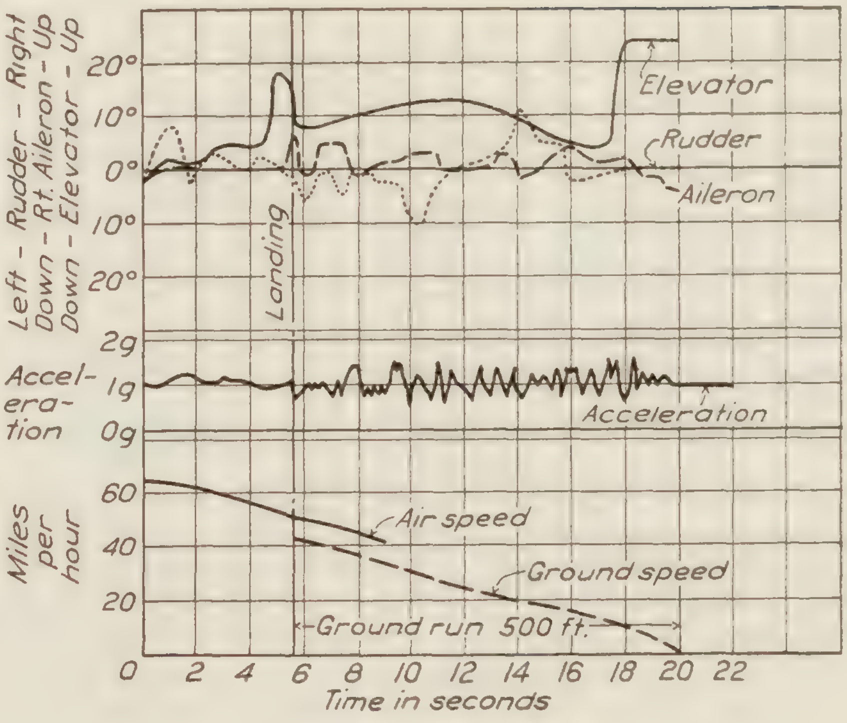


FIG. 3a.—Landing. JN-6h

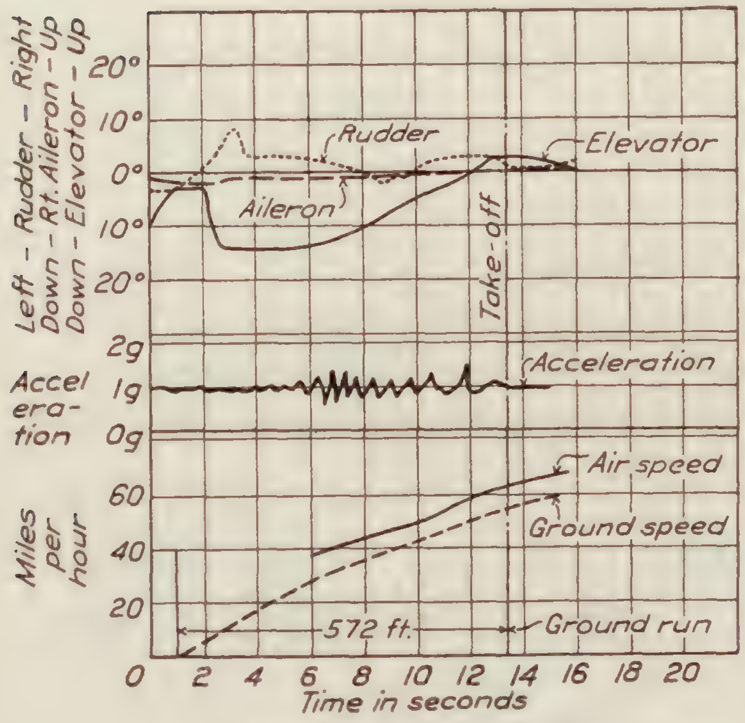


FIG. 4.—Take off. MB-2

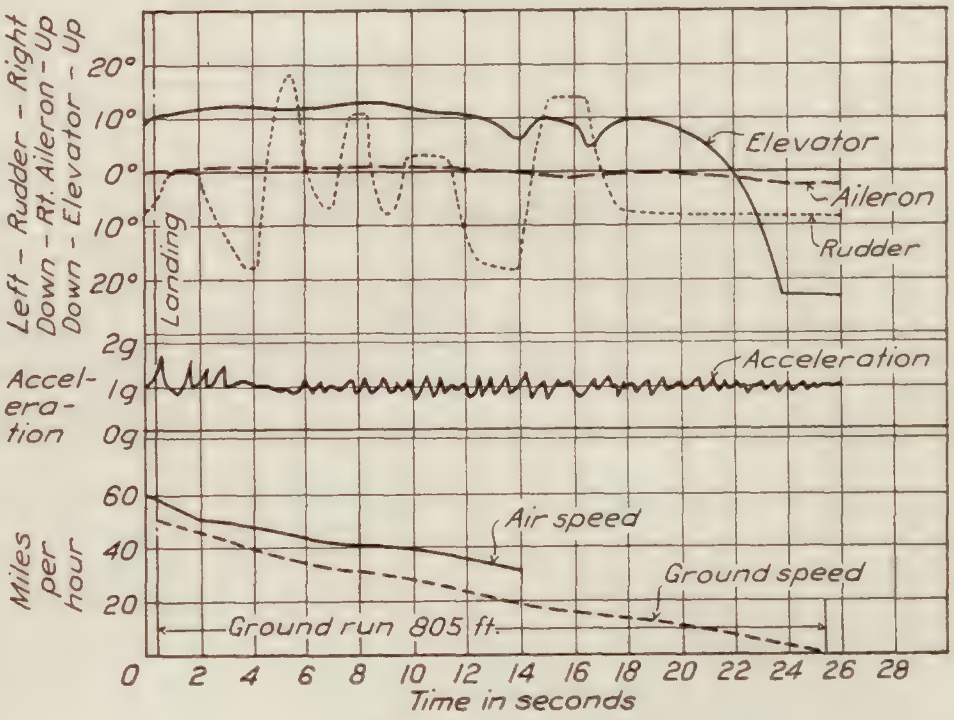


FIG. 4a.—Landing. MB-2

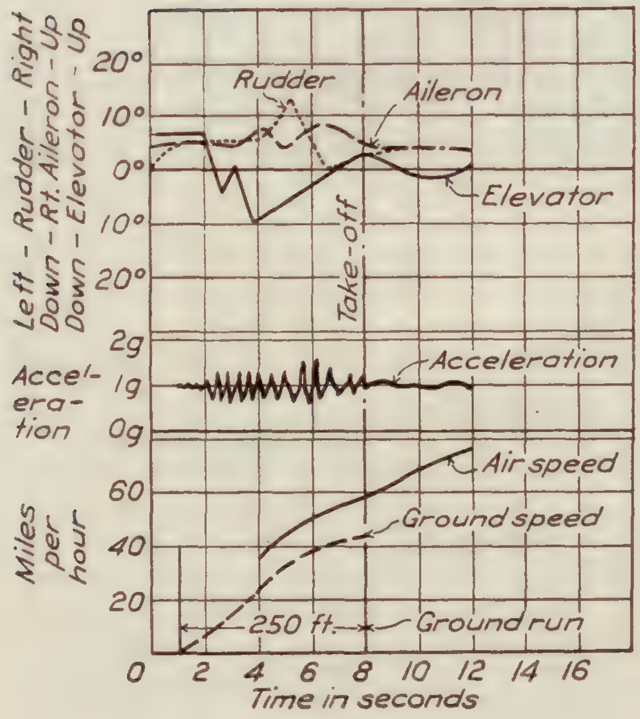


FIG. 5.—Take off. MB-3

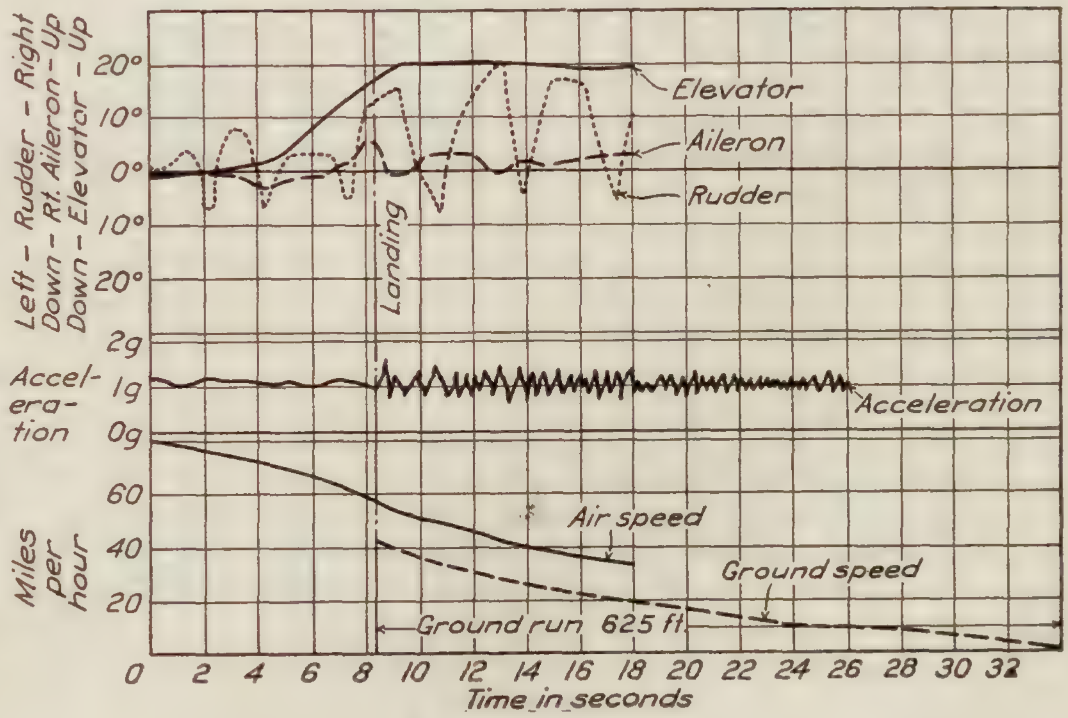


FIG. 5a.—Landing. MB-3

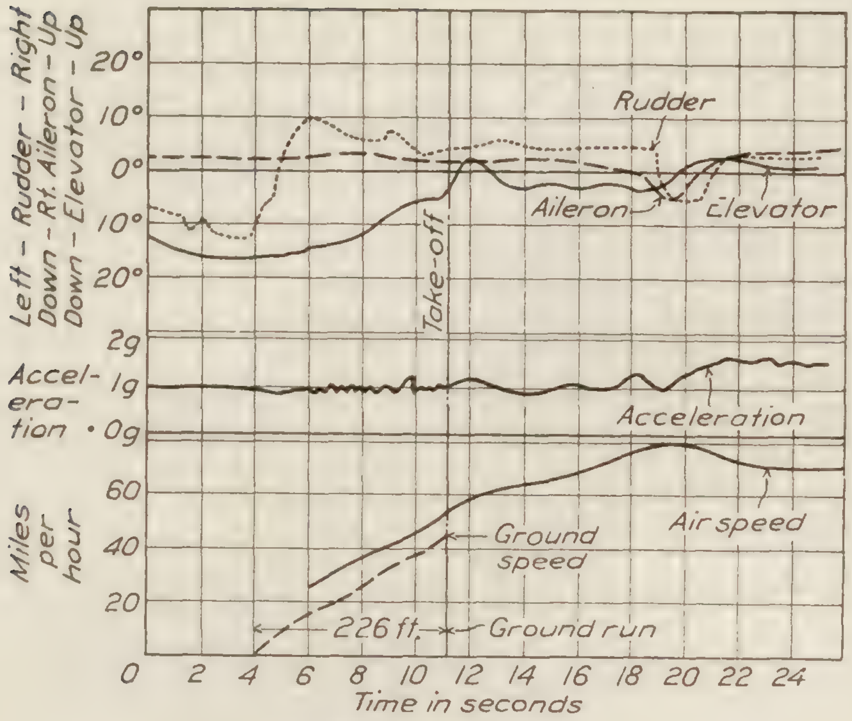


FIG. 6.—Take off. SE-5a

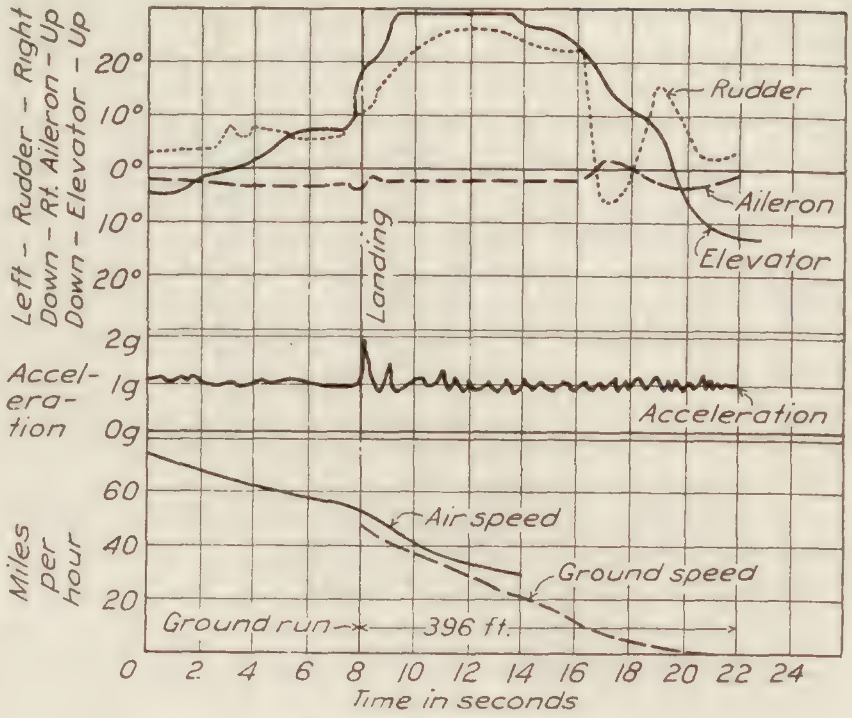


FIG. 6a.—Landing. SE-5a

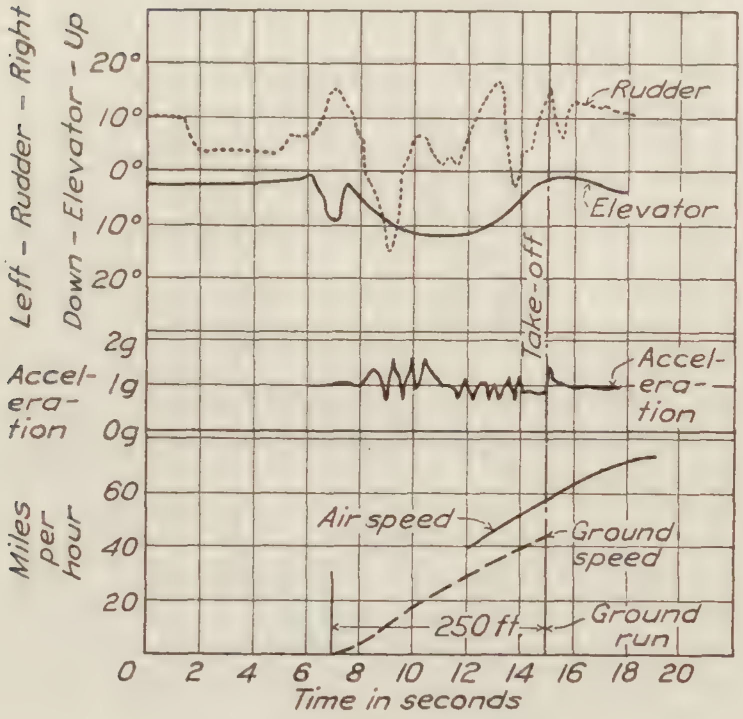


FIG. 7.—Take off. SPAD-VII

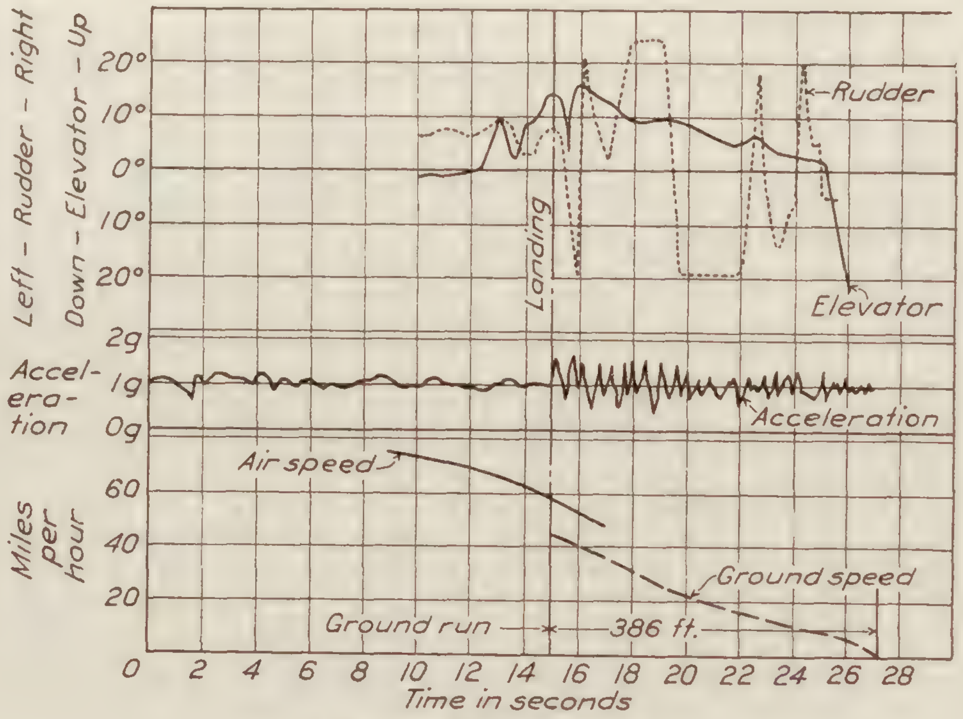


FIG. 7a.—Landing. SPAD-VII

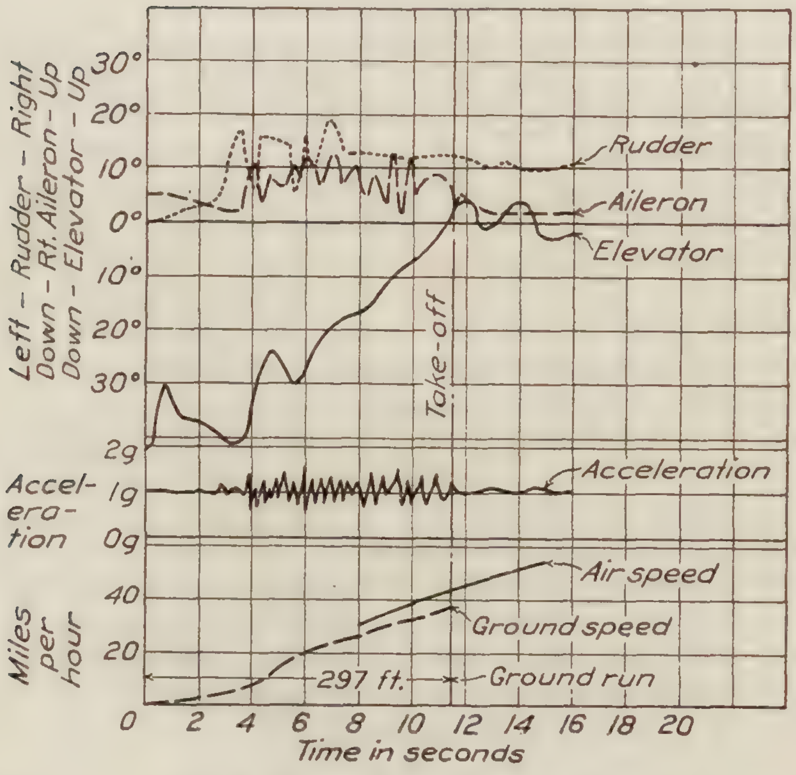


FIG. 8.—Take off. Sperry Messenger

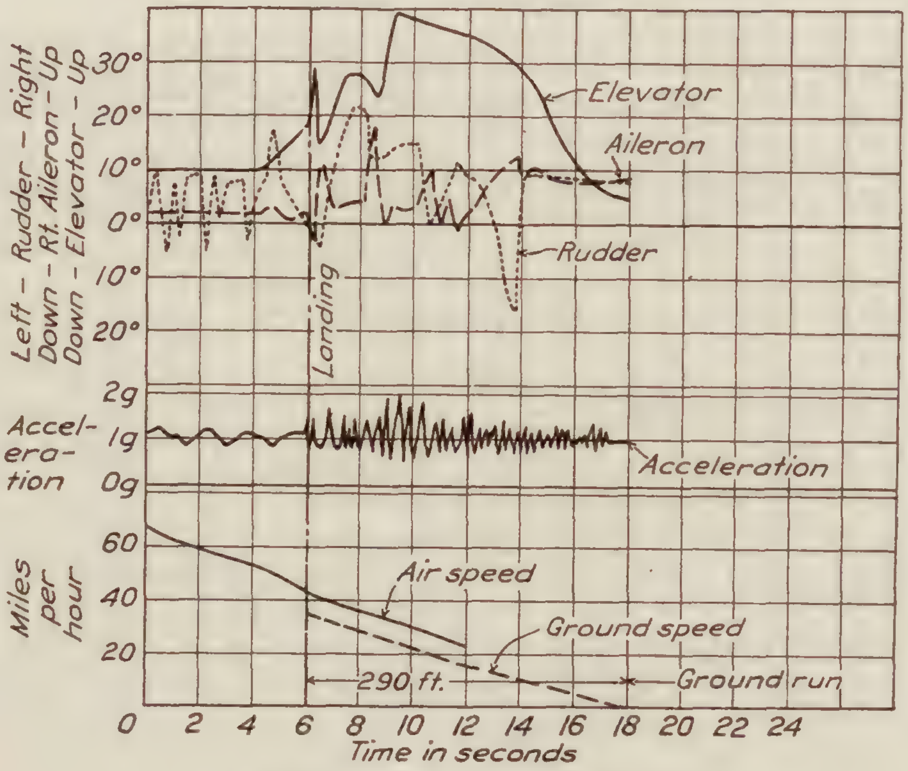


FIG. 8a.—Landing. Sperry Messenger

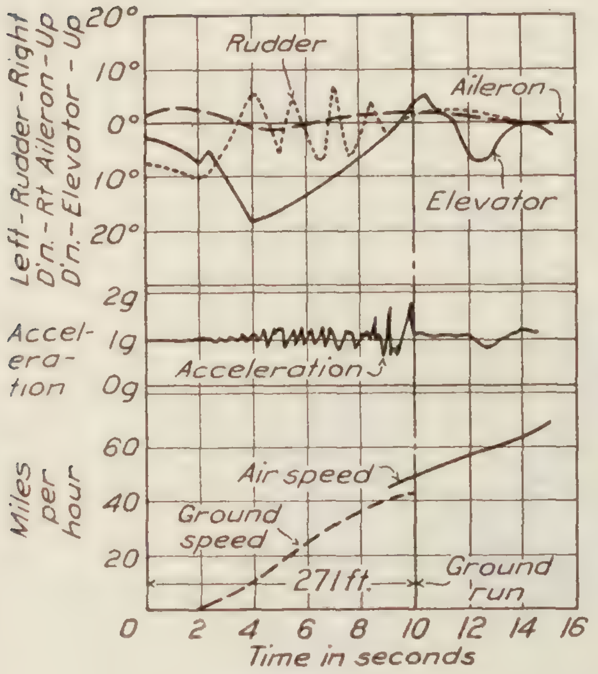


FIG. 9.—Take off. VE-7

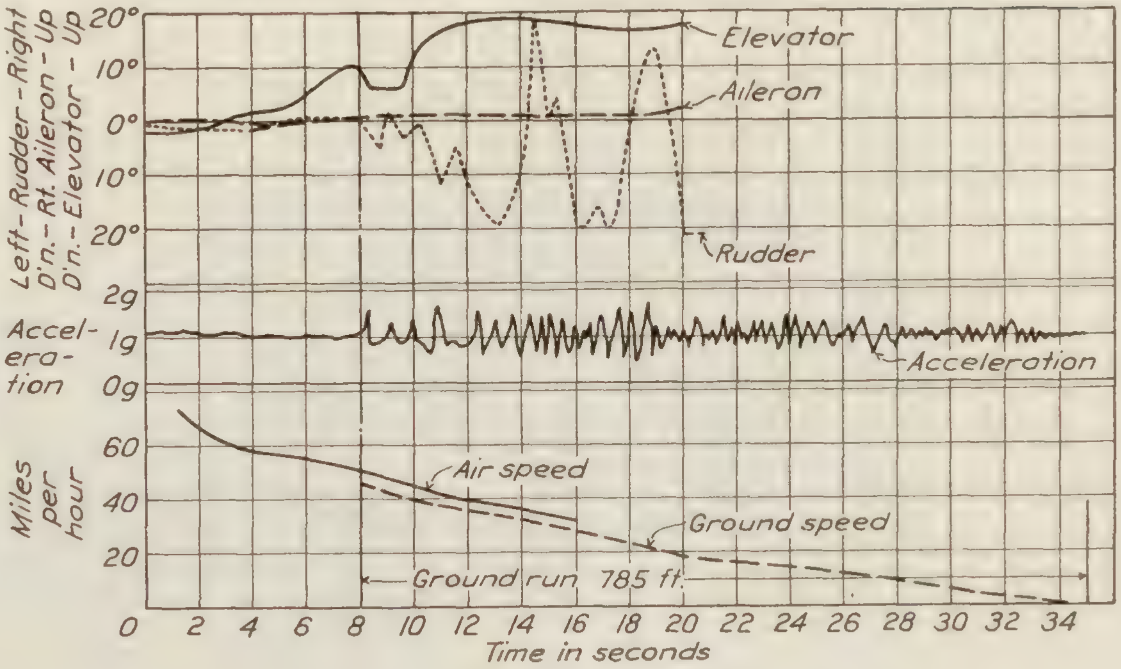


FIG. 9a.—Landing. VE-7

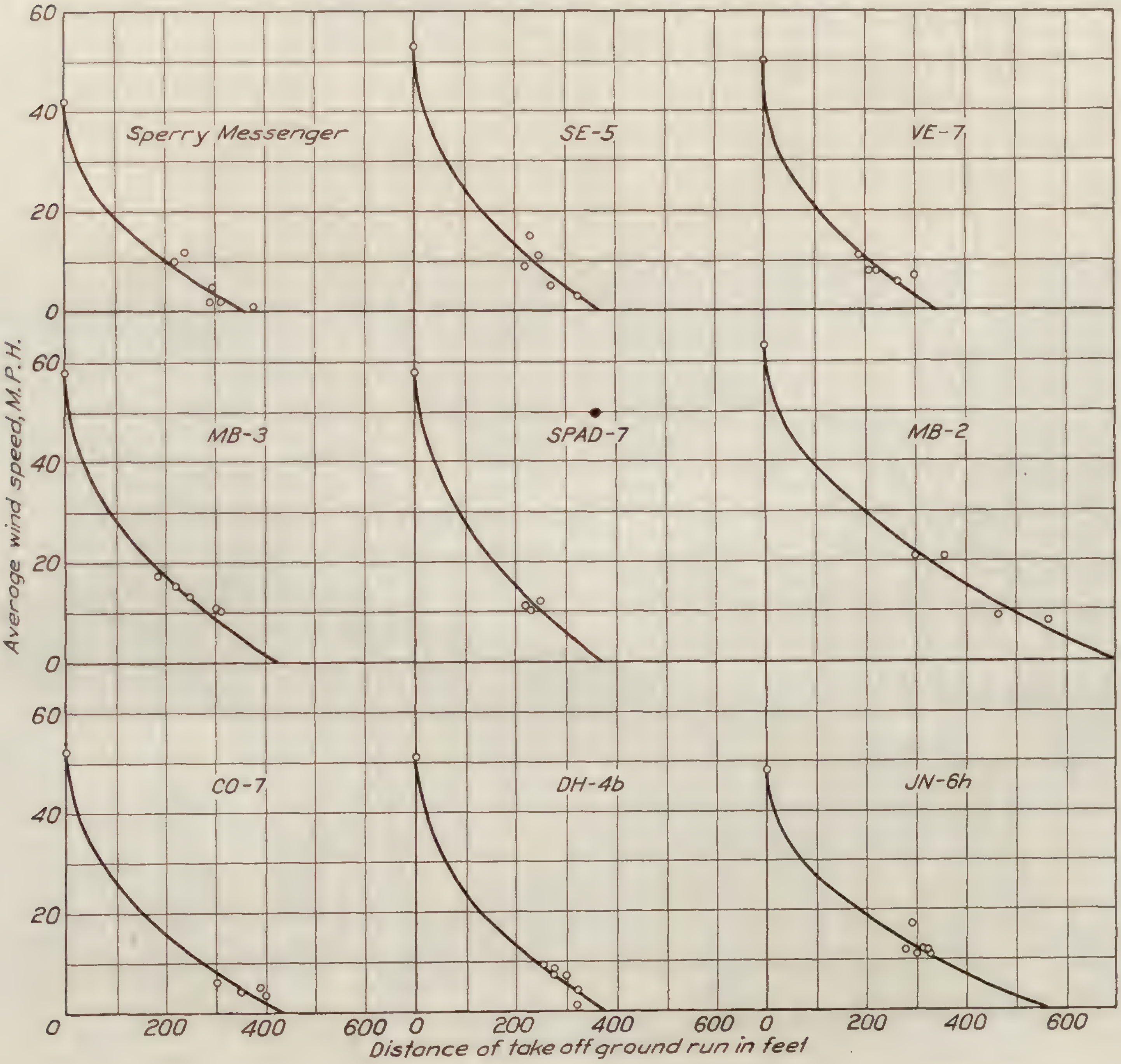


FIG. 10.—Take-off ground run versus wind speed

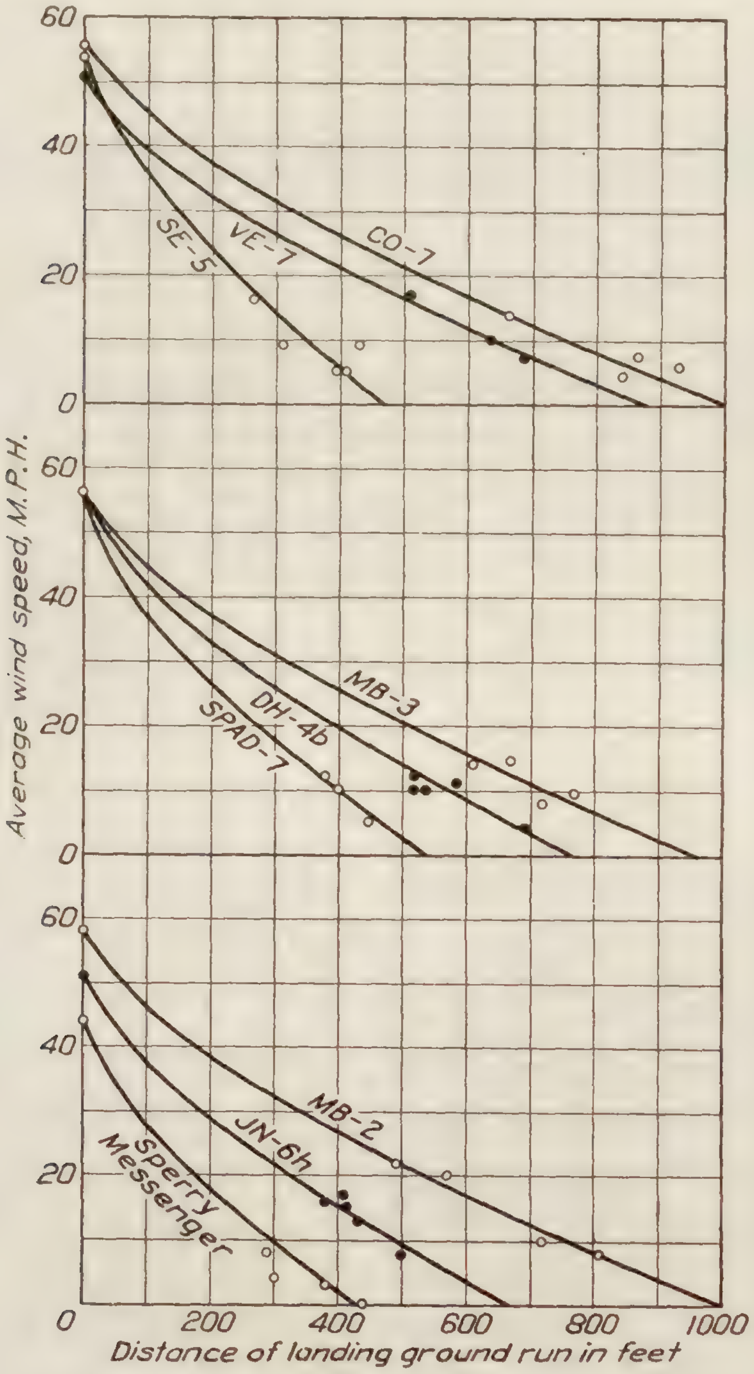


FIG. 11.—Landing ground run versus wind speed

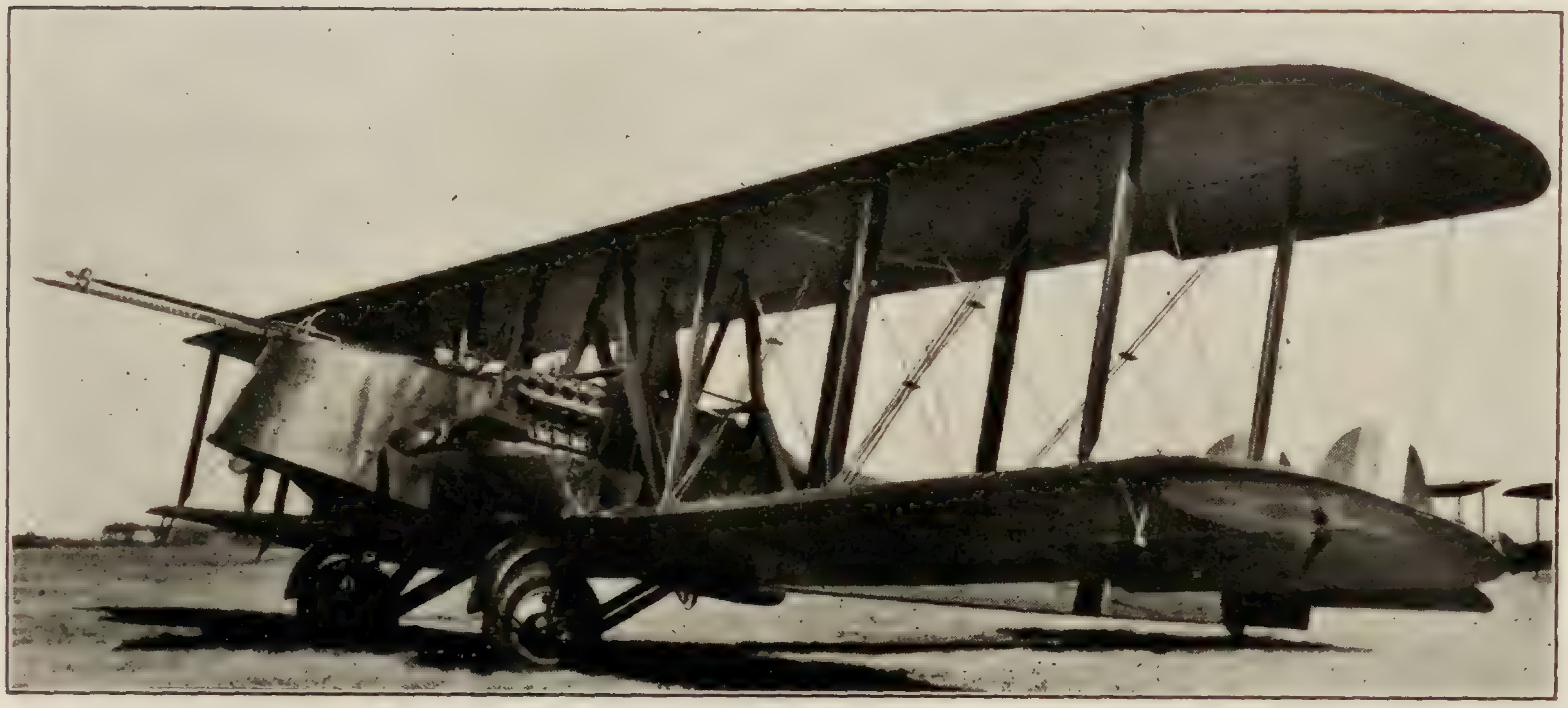


FIG. 12.—Martin Bomber MB-2 ready for landing and take-off tests, showing installation of air-speed head. (NOTE.—The second boom carried an angle-of-attack instrument which was not used in all tests)

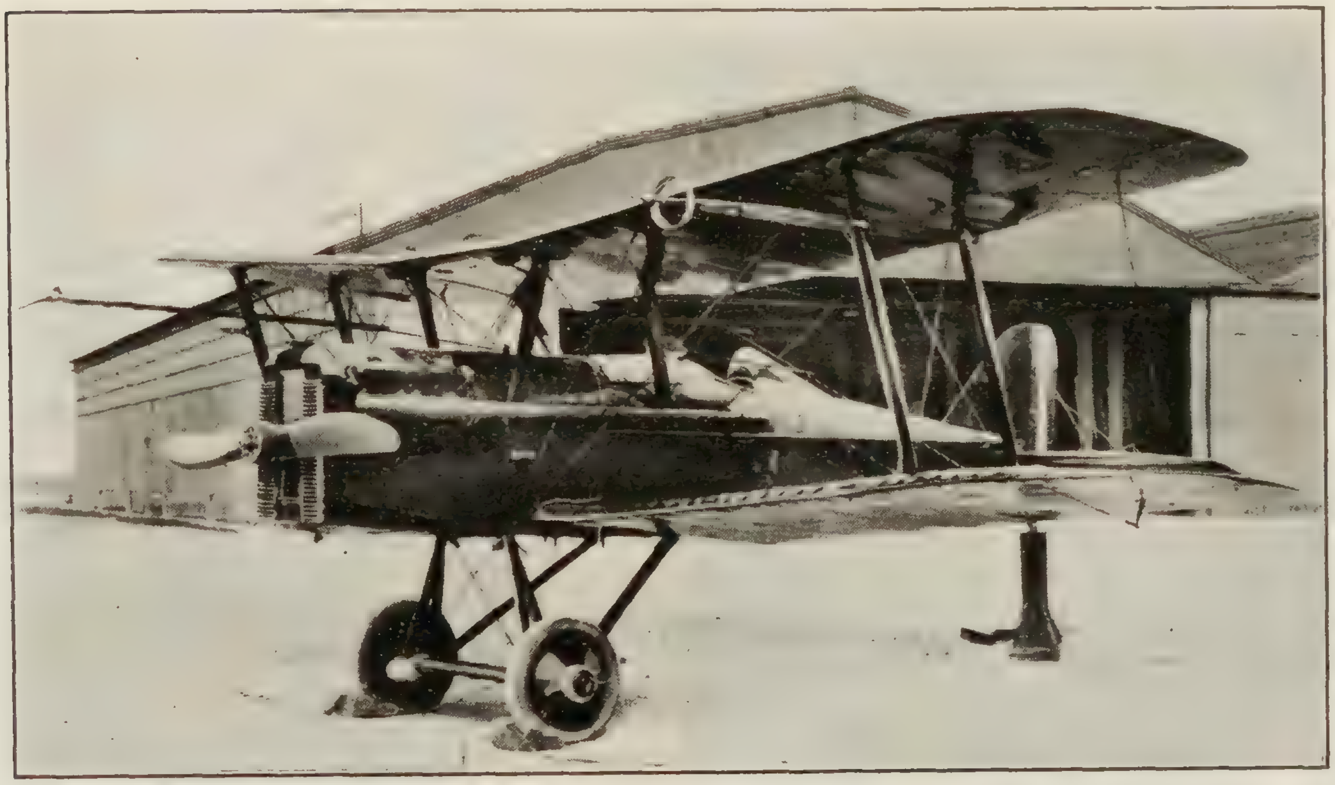


FIG. 13.—SE-5a airplane as prepared for landing and take-off tests, showing ground-speed recorder on wheel, air-speed head on left strut, and angle-of-attack instrument on right. (NOTE.—The angle-of-attack instrument was not used in all tests)

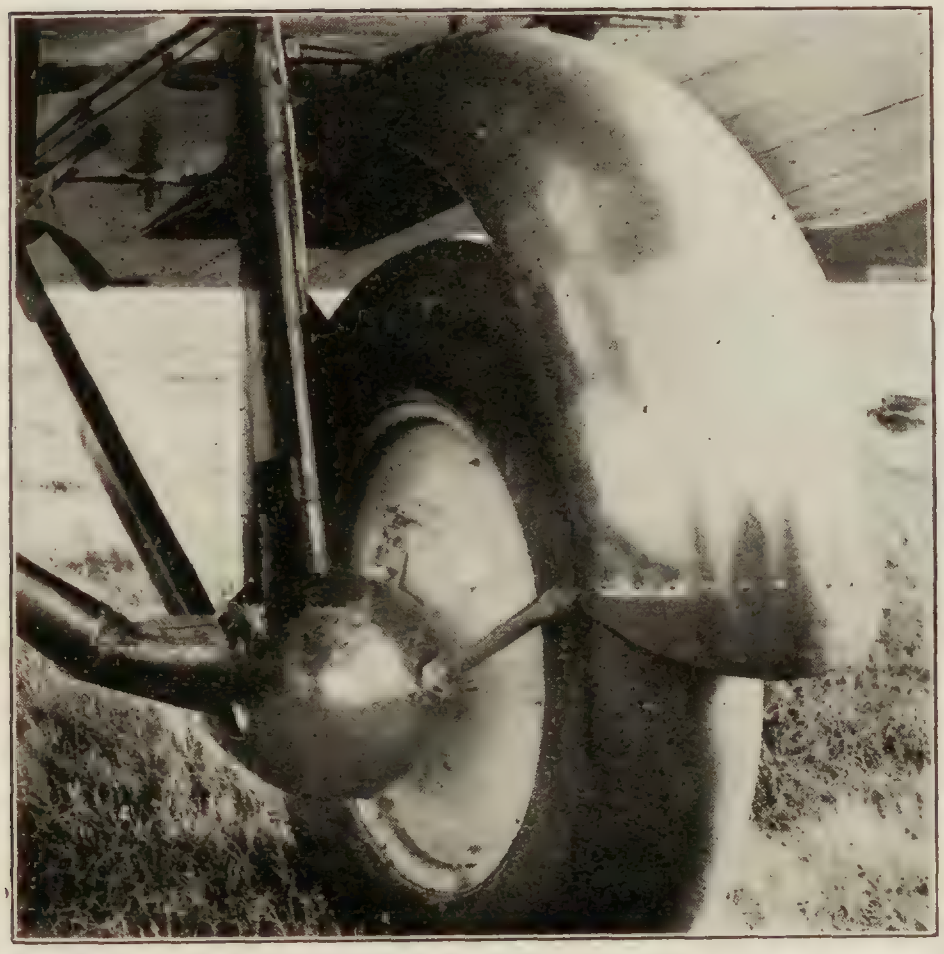


FIG. 14.—Ground-speed recorder installed on Martin Bomber MB-2, showing cam attached to wheel fairing

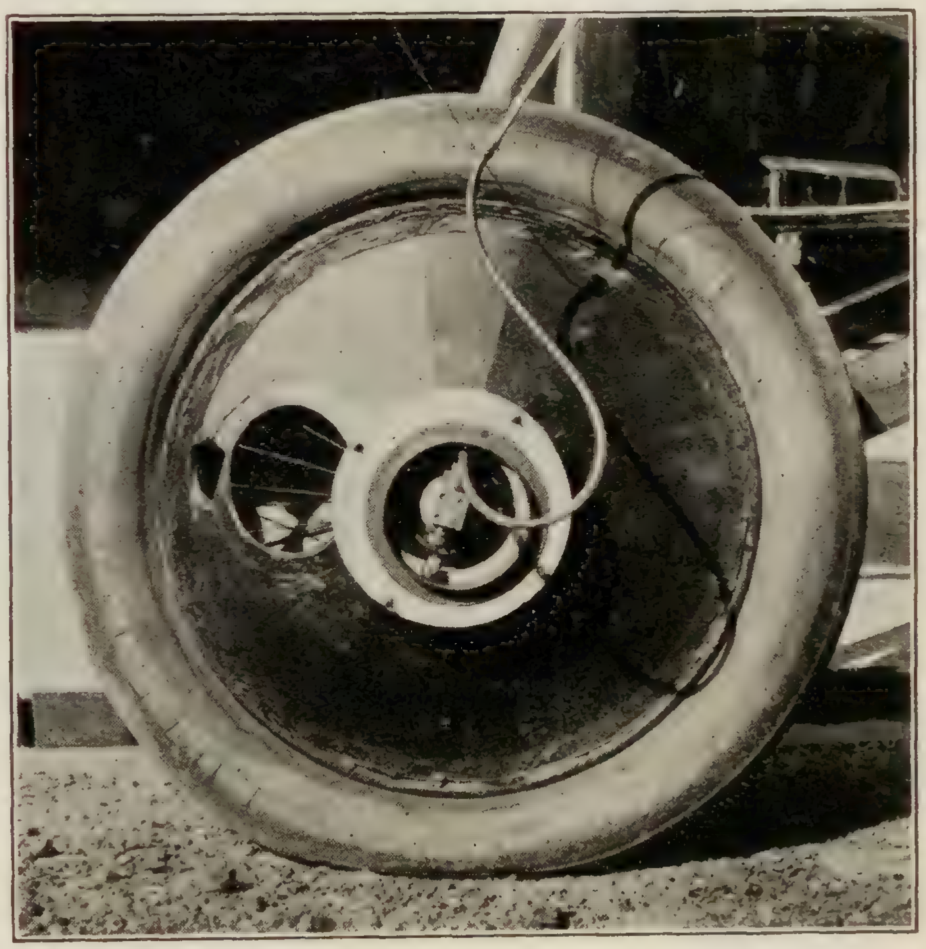


FIG. 15.—Ground-speed recorder on wheel of SE-5a

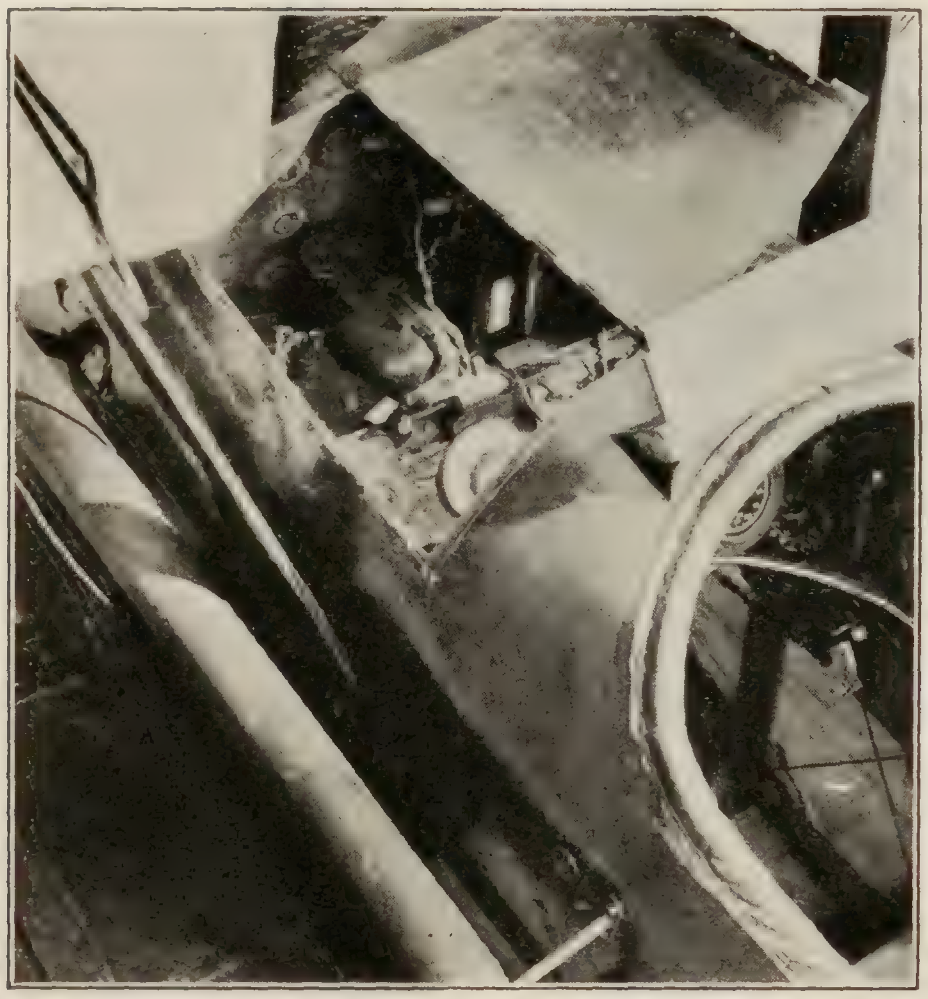


FIG. 16.—Instruments and battery installed in cockpit of SE-5a.

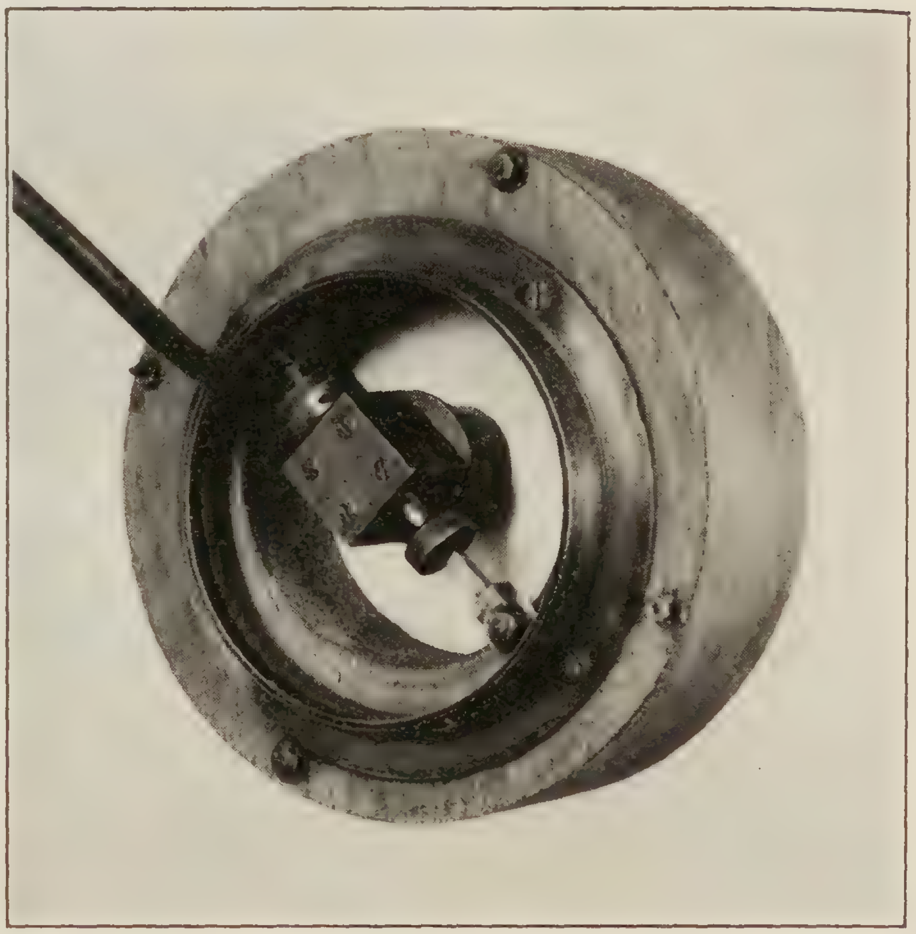


FIG. 17.—The ground-speed recorder showing eccentric race, as installed on all airplanes except the Martin Bomber MB-3

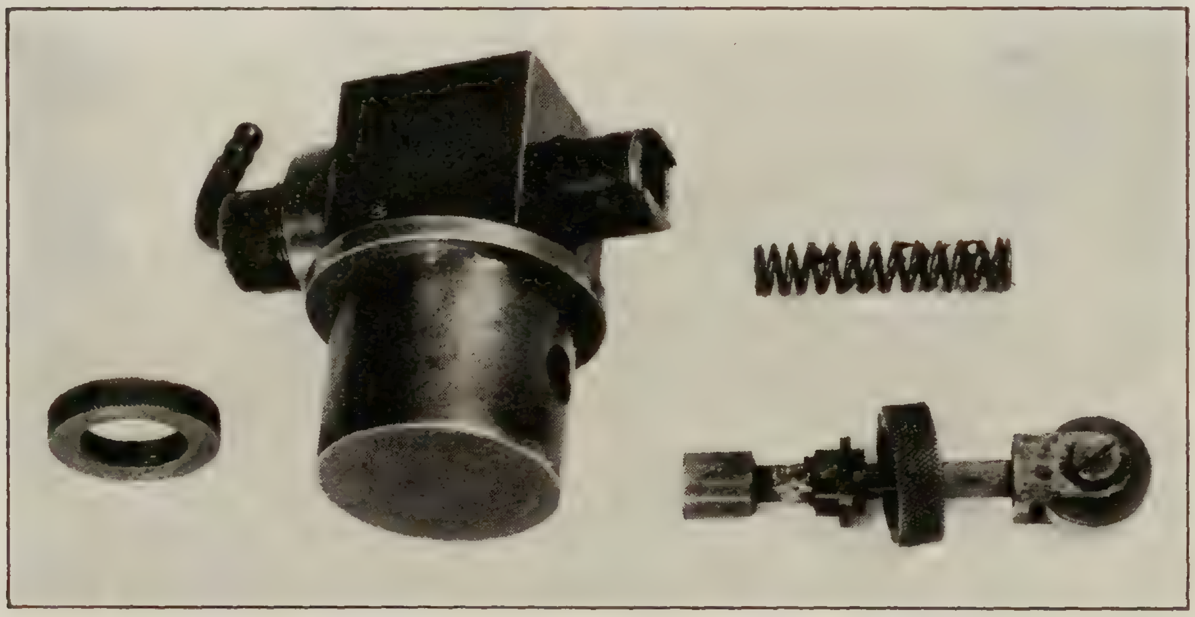


FIG. 18.—The ground-speed recorder disassembled

REPORT No. 250

DESCRIPTION OF THE N. A. C. A. UNIVERSAL TEST ENGINE AND SOME TEST RESULTS

By MARSDEN WARE
Langley Memorial Aeronautical Laboratory

REPORT No. 250

DESCRIPTION OF THE N. A. C. A. UNIVERSAL TEST ENGINE AND SOME TEST RESULTS

By Marsden Ware

SUMMARY

This report describes the 5-inch bore by 7-inch stroke single cylinder test engine used at the Langley Field laboratory of the National Advisory Committee for Aeronautics in laboratory research on internal-combustion engine problems and presents some results of tests made therewith.

The engine is arranged for variation over wide ranges, of the compression ratio and lift and timing of both inlet and exhaust valves while the engine is in operation. Provision is also made for the connection of a number of auxiliaries. These features tend to make the engine universal in character, and especially suited for the study of certain problems involving change in compression ratio, valve timing, and lift.

Incidental to investigations of carburetor and fuel injection engine problems considerable data have been obtained which indicate the effect of changes of compression ratio on friction horsepower and volumetric efficiency. From this and some other work, it appears that with a change in compression ratio from 5 to 13, the friction horsepower obtained by motoring the engine increases by about 15 per cent. The volumetric efficiency of the engine was found to remain practically unchanged between compression ratios of 5.3 and 7.3 with carburetor operation and between 9.5 and 13 with fuel-injection operation.

The results of some tests are presented also that show the power obtained when operating as a carburetor engine on aviation gasoline at compression ratios in excess of that which will permit full throttle as a normal engine and controlling detonation by throttling the intake charge and by varying the inlet valve timing. For fixed compression ratios in these tests throttling gave the least power while variation of the inlet valve closing time with the opening time kept fixed gave the greatest power for the conditions tried.

INTRODUCTION

In order to obtain reliable results from laboratory research, it is necessary to control all variables not under investigation. When dealing with internal combustion engine problems, this is usually very difficult to do. For example, if, in the examination of the effect of a change of compression ratio on engine performance the compression ratio were varied by changing pistons, it would be difficult to obtain the same fit of pistons and rings and to insure identical conditions of lubrication and cooling in the various tests. In addition, atmospheric conditions of pressure, temperature, and humidity would probably change while such alterations were being made and would need to be taken into consideration in the analyses. These difficulties can be eliminated by using an engine specially constructed for changing quickly the variables under investigation without changing other variables.

For the tests mentioned in the previous paragraph, most of the incidental variables would be practically eliminated for direct and succeeding observations if the compression ratio could be altered in a few seconds time and without changing pistons. By the use of suitable auxiliary equipment for the control or the measurement of humidity, pressures, and temperatures of the air and the temperatures of the oil and water, the effects of these variables may be eliminated or determined for protracted series of tests.

Arrangements can be made for the ready alteration of other engine variables and for the connection of various accessories, thus providing a unit suitable for carrying on a large variety of internal-combustion engine research problems with greater facility and with greater reliability of results than would be possible otherwise.

PART I

DESCRIPTION OF THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS UNIVERSAL TEST ENGINE

The National Advisory Committee for Aeronautics universal test engine is a single cylinder, four-stroke cycle engine designed especially for laboratory research on internal-combustion engine problems. Figure 1 shows a three-fourths rear view of this engine and Figures 2 and 3 show the general construction. The engine is of rugged design to insure long service without detailed attention. Ball and roller bearings are used in place of plain bearings to a large extent tending to stabilize and minimize bearing friction losses. The bore of the engine is 5 inches and the stroke is 7 inches. There are two exhaust valves and two inlet valves all of the same size. The valves are operated by rocker arms from overhead camshafts.

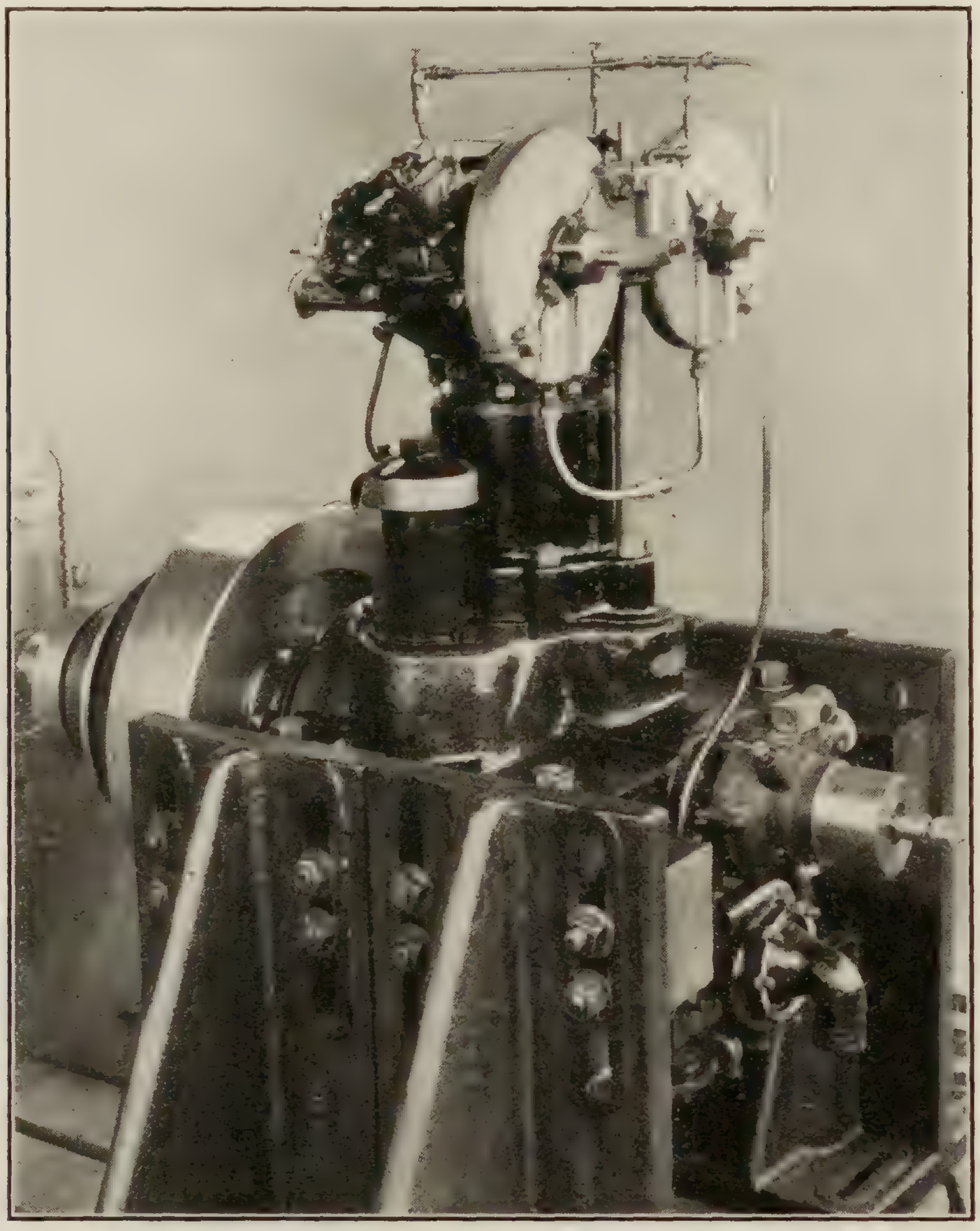


FIG. 1.—N. A. C. A. universal test engine

Provision is made for altering, during operation, the compression ratio and the opening angle, closing angle, and the lift of both the exhaust and inlet valves. Control of these variables is arranged so that each may be altered independently of the others. The compression ratio may be changed from 4 : 1 to between 13 and 15 : 1 according to the valve lift used and with the piston shown. The opening and closing time adjustments of the inlet and exhaust valves have ranges of 50° each, so that the valve opening periods may be increased a total of 100° from a minimum of about 200°. The timing corresponding to the minimum position may be

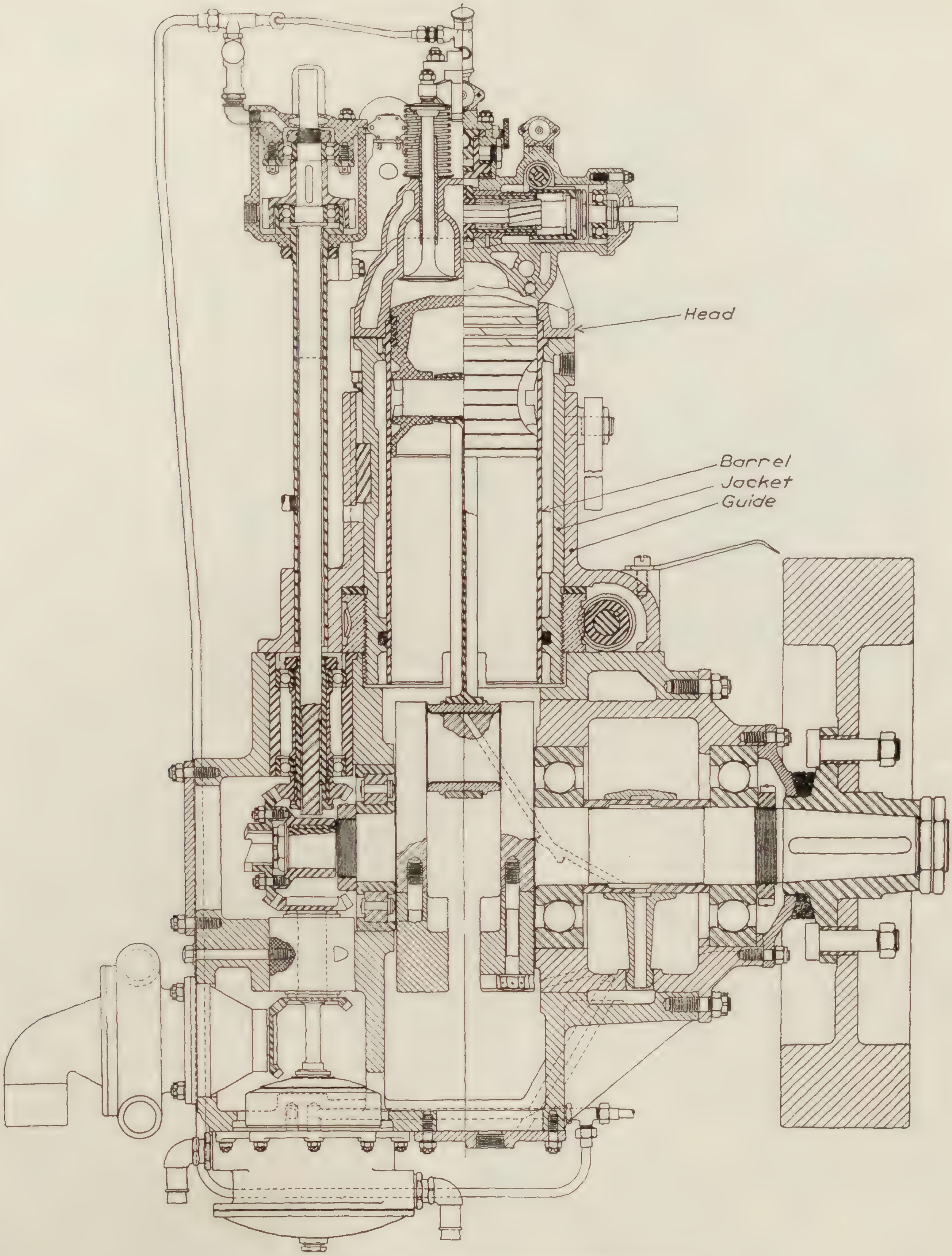


FIG. 2.—N. A. C. A. universal test engine—longitudinal cross section

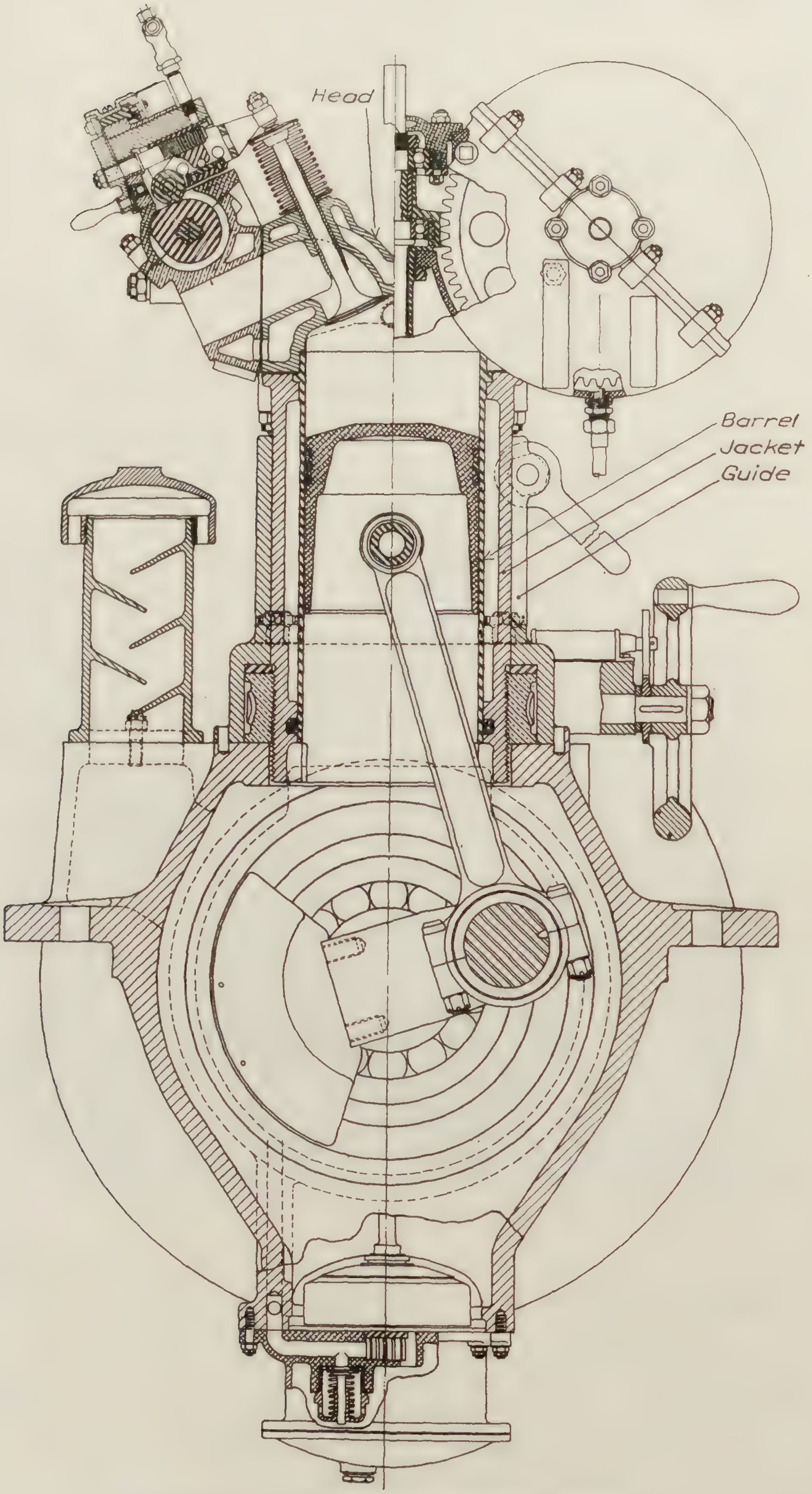


FIG. 3.—N. A. C. A. universal test engine—transverse cross section

altered by changing the setting of the valve operating gear train in the usual manner. The inlet valve lift may be changed from $\frac{7}{32}$ to $\frac{7}{16}$ inch and the exhaust valve lift from $\frac{7}{32}$ to ½ inch.

The engine construction provides for the connection of various accessory apparatus such as ignition timer, fuel injection pumps, pressure indicating instruments, etc.

COMPRESSION RATIO AND VALVE-TIMING CONTROLS

The mechanisms used for changing the compression ratio and the valve timing are probably the most interesting features of the engine and will be described first.

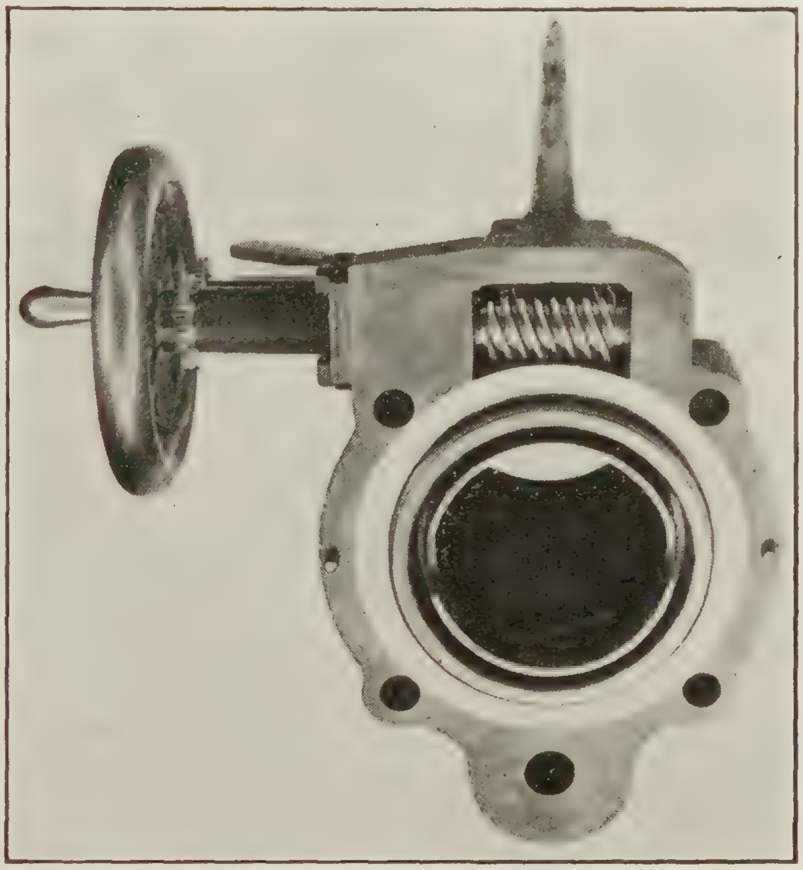


FIG. 4.—View of cylinder guide, jacket, and barrel from bottom, with handwheel and mechanism for effecting change of compression ratio

The compression ratio is varied by moving the cylinder unit vertically, the stroke of the piston remaining fixed, thus changing the clearance volume. The manner in which this is accomplished can be seen by examination of Figures 1, 2, 3, and 4.

There are four main parts to the cylinder construction: The guide, jacket, barrel, and head. The jacket, barrel, and head form an assembled cylinder unit that is movable with respect to the crank case and guide for the purpose of varying the compression ratio. The guide is bolted rigidly to the crank case and provides the means for guiding and fastening the movable cylinder unit. The barrel fits within the jacket, which in turn fits within the guide.

Threads formed on the outside and bottom of the cylinder jacket engage an internally threaded ring, which surrounds the jacket and is restrained from moving vertically by the guide. Rotation of the ring will, therefore, cause the cylinder and head to be raised or lowered according to the direction of rotation, the jacket being prevented from rotating by means of a key fitted permanently in the cylinder jacket, but free to slide in a keyway cut in the cylinder guide. The ring is rotated by a worm meshing with teeth formed on the outside of the ring, a handwheel mounted on the same shaft with the worm providing manual control.

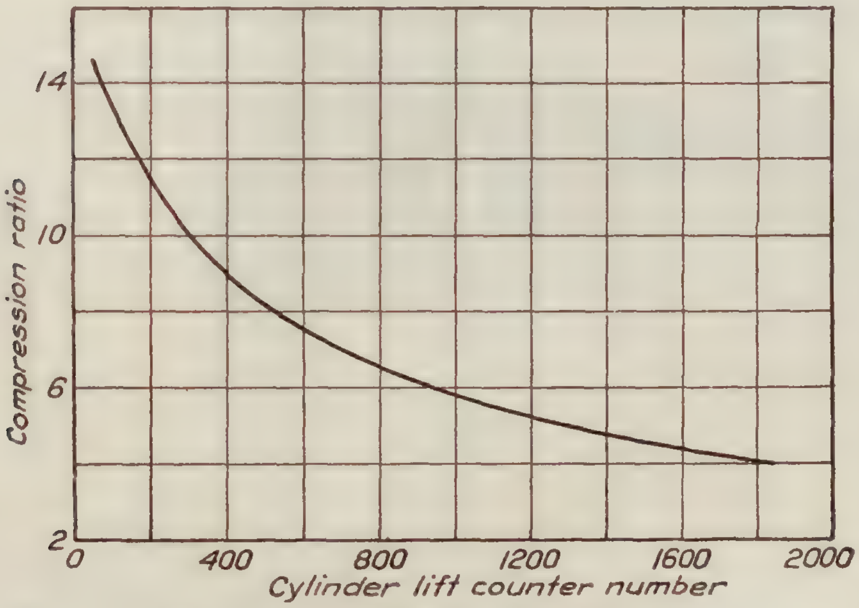


FIG. 5.—Calibration curve of cylinder lift counter

In order to relieve the threaded ring from the necessity of taking the entire explosion load while power tests are being made, the cylinder jacket is clamped in the guide. For this purpose, the cylinder guide is split vertically and is provided with means for clamping the guide around the jacket by the hand lever located on the side of the guide and immediately above the worm and threaded ring construction and shown in Figures 2 and 3.

A counter is geared to the worm shaft to give the position of the cylinder and head with respect to the crank case. The compression ratio is readily ascertained from the counter reading by use of a calibration curve obtained from actual measurement of the clearance volume at a number of different positions of the cylinder. If it is desired to make a test at a definite compression ratio, the cylinder is moved to obtain the counter reading corresponding to this compression ratio. Figure 5 shows a calibration curve for the piston shown in Figures 2 and 3.

The timing of the opening and closing of the valves is varied by the use of three part cams. The central part of each cam is fixed directly to the cam shaft by means of splines while the two outside parts can be rotated independently with respect to the central part and to each other.

All three parts of the cam have the same contour so that when they are aligned they act as a single broad face cam. Displacements of the outside parts from the aligned position are made in opposite directions so that rotation of one of the outside parts varies the opening point while rotation of the other in the opposite direction varies the closing point. When both outside parts are displaced from the aligned position, the dwells of the three parts form one continuous dwell. The dwell of the movable cam parts must be at least equal to the angular variation of the parts from the aligned position. In this engine the dwell of the inlet cam is 50 crank shaft degrees and the dwell of the exhaust cam is 80 crank shaft degrees with both inlet and exhaust cams aligned. Figure 6 shows a cam shaft assembly with the three cam parts nearly aligned; Figure 7 shows the three parts at their maximum displacement position.

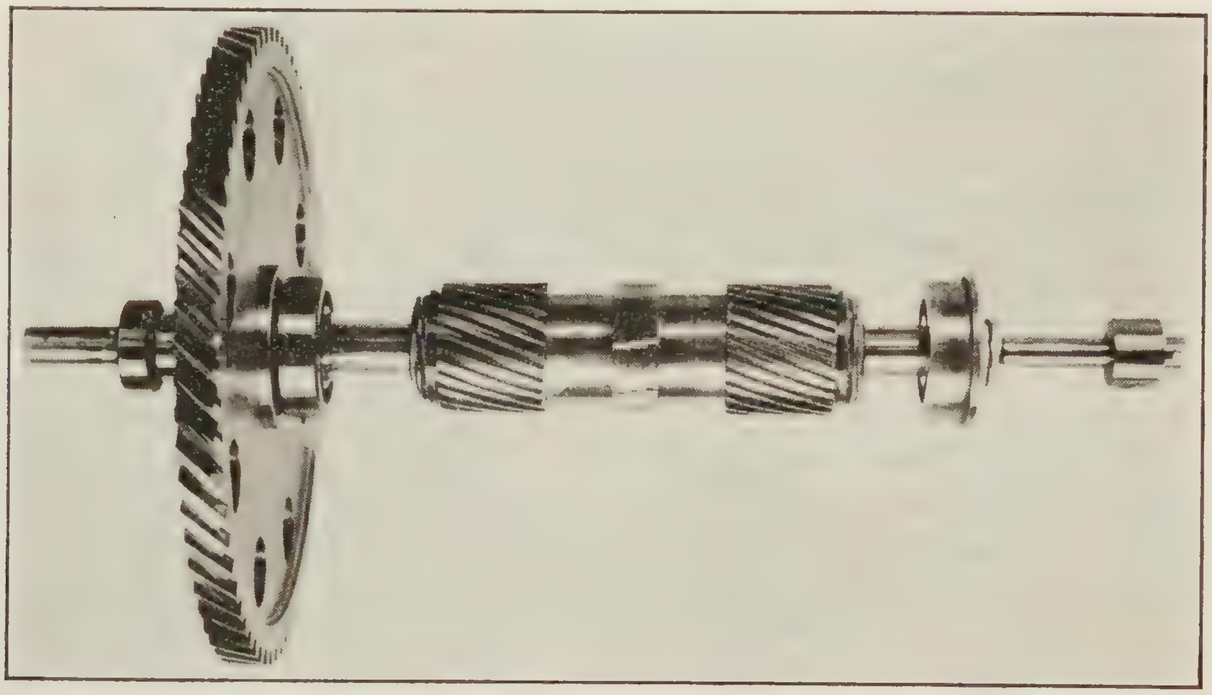


FIG. 6.—Camshaft assembly—cam parts displaced slightly from aligned position

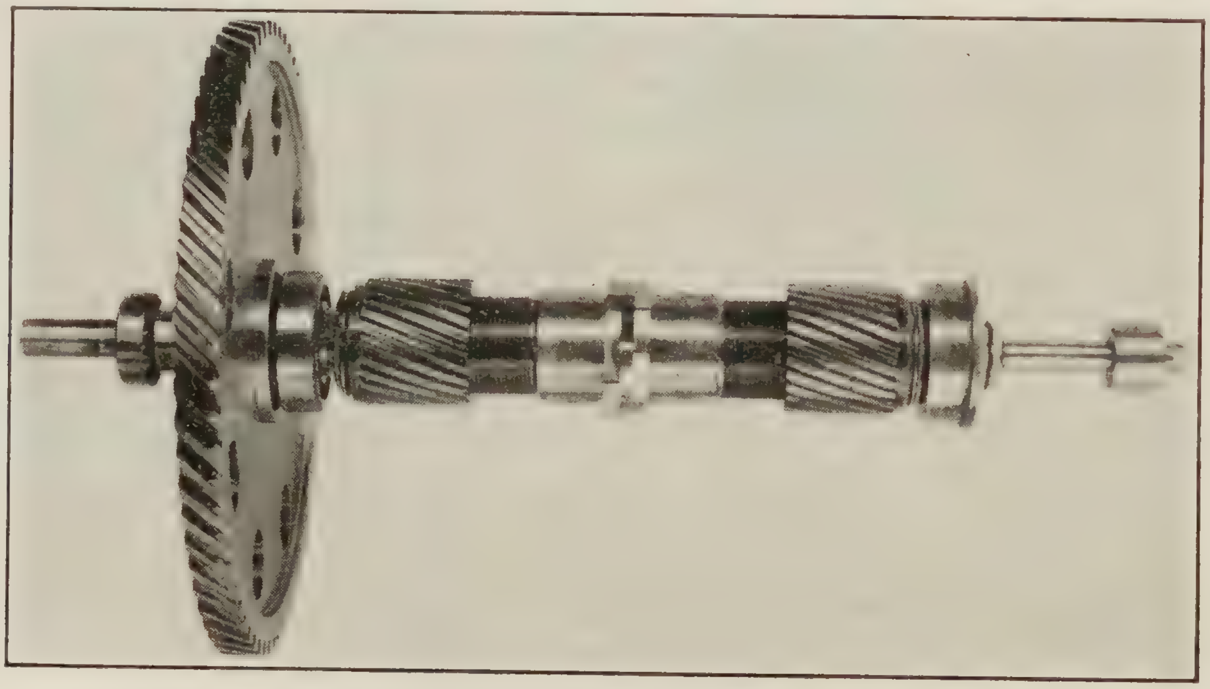


FIG. 7.—Cam-shaft assembly—cam parts displaced their maximum amounts from aligned position

Figure 8 is a sectional view of the operating mechanism. Each outside part of the cams is formed on the end of a sleeve, A, splined internally with helical splines. A bronze bushing, B, surrounding each sleeve, A, and pinned to the cam shaft housing, C, retains the parts of the cams in their proper axial location on the cam shaft and serves as a bearing for the cam shaft unit. Another sleeve, D, is located between the cam shaft and the sleeve that carries the outside cam part. This sleeve slides on straight axial splines on the cam shaft, E, while at the same time external helical splines cut on the outside of D engage internal helical splines in A.

As a result of this spline construction, axial movement of sleeve, D, will cause relative rotation between the cam shaft, E, and the sleeve, A. Since the center part of the cam, F, is splined directly to the cam shaft, the outside part of the cam, A, will be rotated relative to the center part, F, and the valve opening or closing point will be changed according to which outside part is rotated.

Sleeve, A, and intermediate sleeve, D, rotate with the cam shaft when the engine is in operation. Since it is desired to vary the valve timing while the engine is in operation, it is necessary to provide for the axial movement of sleeve, D, by some method that will permit its continued rotation during the adjusting operation. A third sleeve, G, provided with an internal flange, serves as a shifting collar for sleeve, D. Internal threads are provided on sleeve, G, which engage with threads formed on stationary sleeve, B, for a considerable portion of its length. Gear teeth cut on the outside of G mesh with a small hand operated worm, H. Rotation of the worm causes G to move axially with respect to the cam shaft in turn shifting D on the cam shaft and causing relative displacement between the parts of the cam whether the cam shaft is turning or is stationary.

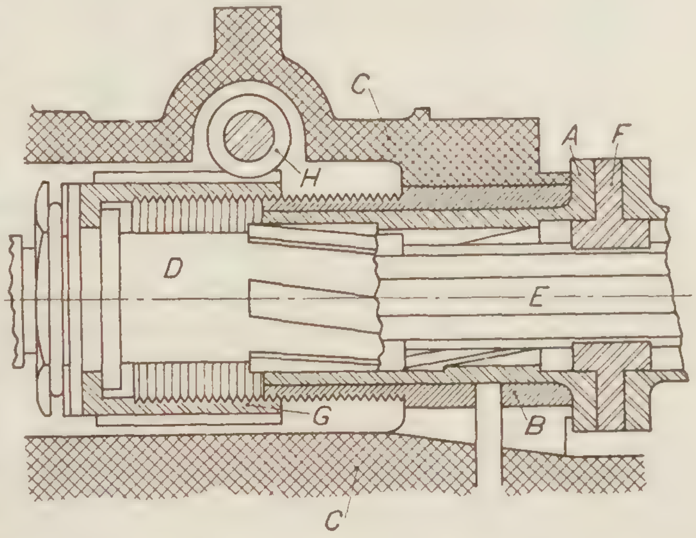


FIG. 8.—Detail of mechanism for making cam adjustment

The cams operate the valve by direct action on rocker arms, each pair of valves being actuated by a single rocker arm.

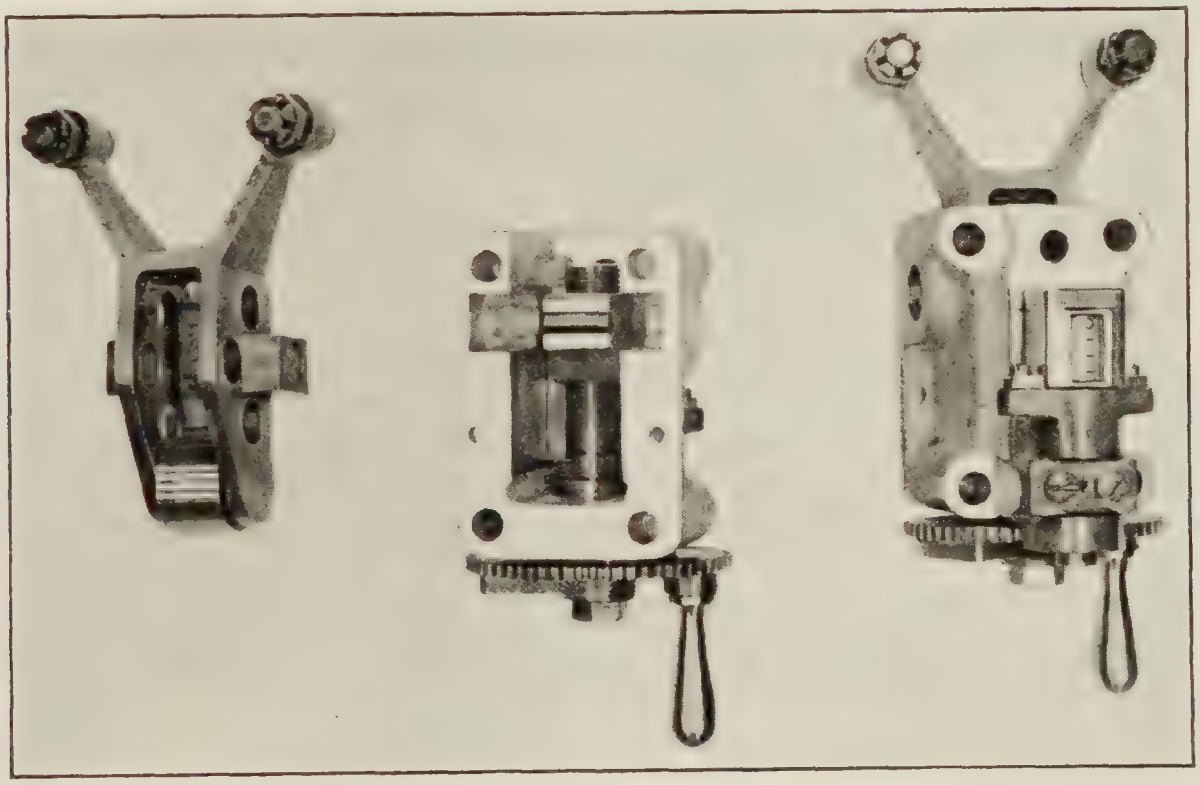


FIG. 9.—Rocker arm and housing

Variation of valve lift is effected by changing the position of the rocker arm fulcrum by means of the mechanism shown in Figures 3 and 9. The fulcrum is formed by a small hardened pin bearing against a hardened plate fastened to the rocker arm, the line of contact between the pin and the plate forming the fulcrum axis. The rocker arm is constrained from changing its position with respect to the valve and cams by trunions machined on the outside of the rocker arm carried in blocks free to move in the rocker arm housing only and parallel to the valve stem axis. The hardened pin is mounted in a block that is movable with respect to the rocker arm housing. The fulcrum point is changed by turning a small handwheel mounted on a threaded shaft, the threads in turn producing linear movement of the block carrying the fulcrum pin.

All the handwheels controlling the valve functions are geared directly to revolution counters, the counter readings giving the value of the timing and lift of the valves.

GENERAL CONSTRUCTION

The engine has heavy mounting flanges integral with and extending the full length of the cast-iron crank case. This construction permits of flexibility in the mounting of the engine on dynamometer equipment with the use of the usual parts of this equipment for the testing of engines and without alteration of the crank case or provision of a special base.

The crankshaft is carried by two large ball bearings and one roller bearing. The roller bearing is located on the gear end of the crank shaft and is mounted directly in the main crank case casting. The two ball bearings are located on the fly wheel end of the crank shaft and are mounted in a cylindrical cast-iron cage which is mounted in and bolted to the main crank case casting. Removal of this cage effects removal of the crank shaft and bearing assembly from the crank case.

The cylinder structure has been described partially under the description of the compression ratio changing mechanism. A long annular space is formed between the jacket and the barrel which provides for circulation of the cooling water. The cylinder head has a cored water jacket with no internal communication with the cylinder jacket. This construction permits separate control of the flow of the cooling water to the cylinder and head and consequently permits maintaining different water temperatures for the two parts. The guide, jacket, and head are iron castings and the barrel is a steel forging.

Three openings are provided in the head for the insertion of spark plugs, fuel injection valves, pressure indicating devices, etc. These openings are provided with standard metric spark plug threads. Two openings are located on opposite sides of the head; the third opening is located in the center of the head. Several threaded openings into the jacket and head are provided for connecting cooling water fittings.

The piston and connecting rod shown in Figures 2 and 3 are standard Liberty engine parts.

Two cam shafts are provided, one for the inlet valves, the other for the exhaust valves. These two shafts are driven from a vertical shaft by helical gears. The vertical shaft is in turn driven by the crank shaft through bevel gears. The vertical shaft bevel gear is mounted directly on a relatively short hollow shaft having internal splines which engage splines on the lower end of the vertical shaft proper. This construction permits the upper shaft to move vertically with the cylinder. The crank shaft bevel gear furnishes also the drive means for the water and oil pumps.

The ends of both cam shafts and the top end of the cam driving vertical shaft extend outside their housings to provide driving means for various auxiliaries, such as ignition timing mechanisms, indicators, etc. The crank shaft bevel gear is splined internally to provide a driving means for other auxiliaries, such as fuel injection pumps, which may be fastened to the rear of the engine base.

The oil pump is a combined scavenging and pressure pump. The scavenged oil is carried off to an external reservoir. The oil from the pressure side of the pump is carried through drilled passages in the base to the front of the engine. The path divides at this point, one path leading to the cam shaft mechanism, where the flow to the various parts is regulated by three sight-feed adjustable oilers, the other path leading to the crank shaft through a bronze casting that rides on the crank shaft. Passages are drilled in the crank shaft for the lubrication of the connecting rod bearing. The bearing in the crank case, the piston pin, and piston are lubricated by oil thrown off the connecting rod bearing.

ENGINE TEST EQUIPMENT

In the use of this engine for research, certain auxiliary apparatus are necessary for measuring various quantities affecting the performance, or entering the performance determinations. While the number and type of such auxiliaries will vary with the kind of work, or the particular investigation undertaken, there are a number that enter into a large percentage of the work and may consequently be considered to be combined with the engine to form a research unit. The chief auxiliary items of equipment used with this engine are an electric dynamometer, a gasometer, fuel and water measuring apparatus, air, oil, and water temperature regulating apparatus, exhaust handling equipment, and special carburetors and fuel injection apparatus.

The electric dynamometer not only serves as a readily adjustable and convenient brake for absorbing the power developed by the engine, but also provides the means for motoring the engine. The torque required to motor the engine or that produced by the engine when it is developing power, appears as torque on the dynamometer field housing. The housing is mounted on ball bearings and therefore can swing free in its support pedestals. An arm fastened to the housing acts on a scale which resists and indicates the torque on the housing. The power developed in power tests or that required in motoring tests is determined from the torque and speed of revolution. The speed of revolution is determined by a tachometer and an electrically operated revolution counter and stop watch.

The gasometer or displacement meter is used in connection with an automatic timing mechanism for giving the time for the consumption of a given volume of air.

Three methods are used in measuring fuel-consumption rates. One method consists of the measurement of the time for the consumption of a given volume of fuel. This method requires frequent determinations of specific gravity of fuel used where weight of fuel is desired. The second method consists of the measurement of the time for the consumption of a given weight of fuel, measures the weight directly, and is used for most work. A third method employs a calibrated orifice where the rate of flow is a function of the loss of head in the passage of the fuel through the orifice. This method is valuable as a means of indicating quickly the approximate rate of fuel flow following carburetor adjustment and is used in conjunction with one of the other more accurate methods.

An electric resistance type air heater is provided between the gasometer and the carburetor to enable the inlet air temperature to be controlled. Oil and water temperature regulating means are provided also for controlling these temperatures. Temperature indicating devices are provided at appropriate locations. A blower and piping system are used to carry the exhaust gases away from the engine and deliver them outside of the building.

In the comparison of the relative performance with two different fuels, a carburetor has been used that has two throttles and two distinct metering systems and float chambers, but a single air inlet and single mixture exit. One fuel, which may form a standard of comparison, is used in one side of the carburetor, while another fuel, which may be the fuel to be compared, is used in the other. The controls of both throttles are carried to the control board, and the operator may change fuels instantaneously by opening one throttle and closing the other.

Fuel injection pumps are attached to the engine for fuel injection engine work. In this work the fuel fed to the pump usually is required to have a pressure of over 100 lb./sq. in. A small gear pump used for this purpose, fuel weighing apparatus, and supply tank are mounted on a stand, forming a compact primary fuel system.

PART II

SOME RESULTS OF TESTS WITH UNIVERSAL TEST ENGINE

An engine of this kind is especially suited for the study of a number of problems that have received some attention in the past, but under conditions which in most cases have, of necessity, included undesirable variables. Of interest among such problems is the effect of changes in compression ratio on volumetric efficiency and engine friction. While this engine has been used very little in the direct study of these problems, considerable data having a bearing on these relationships have been obtained incidental to work on other problems and have been assembled for presentation in this report. Some results obtained in an examination of the ground level operation of the over-compressed engine in which the variable valve timing features entered are also presented.

VOLUMETRIC EFFICIENCY AND COMPRESSION RATIO

Air measurements taken during a large number of tests made in connection with a carburetor engine problem involving a total of 83 observations at compression ratios of 5.3, 6.3, and 7.3 are used in the consideration of the effect of compression ratio changes upon volumetric efficiency. Volumetric efficiency as used in this report is defined as the ratio of the actual volume of air drawn in by the engine on each cycle when reduced to the temperature and pressure conditions of the air at the engine to the displacement volume of the engine. No difference in volumetric efficiency in excess of 1 per cent was noted between the average values for the three compression ratios.

Air measurements taken in connection with a fuel injection compression ignition problem, involving 80 observations and covering compression ratios from 9.5 to 13, show a similar effect.

The results of the two series of tests are not directly comparable since any influence on volumetric efficiency of fuel vaporization on the suction stroke in the carburetor work does not appear in the fuel injection work with the fuel injected near top dead center on the compression stroke. Consequently no attempt is made to estimate the effect over the entire range of compression ratios from 5 to 13. The test conditions in each set were maintained practically constant with sufficient variation in air-fuel ratio in the carburetor runs to permit elimination of the effect of this variable in this analysis. The two sets of results are, therefore, comparable in themselves.

Ricardo gives results of a test of the effect of a change in compression ratio from 5:1 to 7:1 in which the rate of air flow was reduced from 209.5 lb./hr. to 190 lb./hr.—a change of 10 per cent. (Reference 1.) No difference of this magnitude was noted for any of the large number of points providing the information presented in the previous paragraph and it appears evident that in so far as these tests on the universal test engine are concerned the effect of compression ratio on volumetric efficiency, for a considerable change in this ratio, is so small that it is of little practical importance.

ENGINE FRICTION AND COMPRESSION RATIO

A large number of tests have been made in both carburetor and fuel-injection work during which measurements of friction horsepower were made by motoring the engine with the dynamometer. These tests covered compression ratios from 5.3 to 7.3 and 9.5 to 13. The results of these friction measurements plotted against compression ratio, together with a series of independent motoring tests for the complete range of compression ratio from 5 to 13, are given in Figure 10. The independent motoring tests were made with oil and water temperatures maintained by means external to the engine. Four distinct groups of results are given for the same speed of revolution but with oil and water temperature conditions different between the groups although constant for each group.

Curves A and B give friction mean effective pressures obtained from the friction horsepower tests taken immediately after power tests, while curves C and D apply to the independent motoring tests. Curve A is the average curve for the result obtained in connection with full throttle power runs on a carburetor engine problem and was obtained by careful consideration of over 104 test points. Curve B is the average curve for the results obtained in connection with a fuel-injection engine problem and includes 78 test points. Curve C is the average curve of a series of independent motoring tests during which the compression ratio range shown was traversed repeatedly in opposite directions and the observations taken as rapidly as possible. None of the points taken departed over 2 per cent from the curve shown. The two points designated D are data for independent motoring tests, taken some time previous to the other group.

While there is considerable vertical displacement between the groups, they are consistent as regards slope and it is evident that friction horsepower, as measured by motoring tests, increases with increase in compression ratio. The vertical displacement between curves A and B is probably due to a difference in kind and temperature of lubricating oil used in the two groups of tests and to fits of pistons and rings which were changed during the time that elapsed between the two groups of tests. Both curve A and curve B show practically the same rate of increase in friction as curve C over the range of compression ratio covered by A and B. As a result of this, it is assumed that curve C is a fair representation of the order of change in friction with change in compression ratio for observation taken immediately after power runs. This curve shows an increase in friction of 15 per cent for a change in compression ratio from 5 to 13.

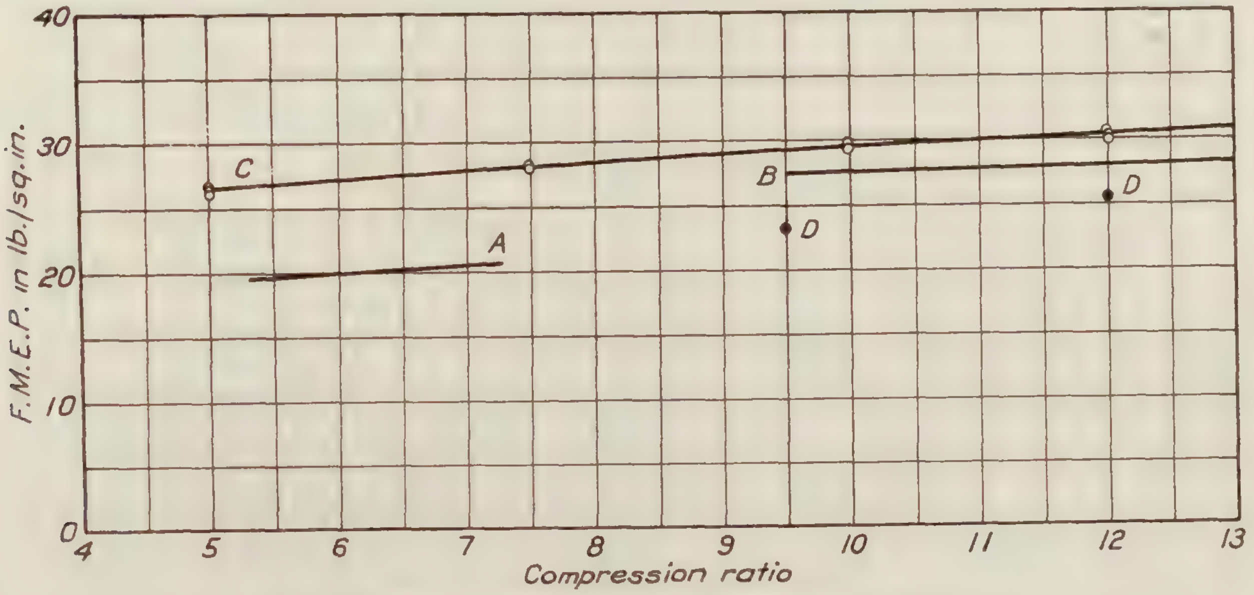


FIG. 10.—Effect of change in compression ratio upon F. M. E. P.

The extent to which these friction results can be used to give the difference between indicated and brake power for actual power operation can not be stated definitely from theoretical considerations alone. In motoring tests, the increase in friction with increase in compression ratio is due primarily to two causes. First, the increased pressures accompanying increased compression ratio will cause greater mechanical friction losses, due primarily to greater piston ring friction and piston side thrust. Second, the operations of suction, compression, expansion, and exhaust during the motoring tests may be such as to require greater work input with increased compression ratio. Due to leakage past the piston and rejection of heat to the jacket, all of the work of the compression stroke will not be returned on the expansion stroke. The difference between the work for these two strokes will increase with increase in compression ratio.

When the engine is under power the conditions are somewhat different. Piston side thrust will increase more with a change in compression ratio when the engine is developing power than in motoring tests where an increase in compression ratio is accompanied by an increase in mean effective pressure. Indicator cards taken under power show the work done by the engine on the compression and expansion strokes and that required to overcome pumping losses on the exhaust and inlet strokes. While there are actual losses due to heat rejection and leakage past the piston during the compression and expansion strokes in power runs, indicator cards taken during power runs do not show the work required as a result of these losses as they do in motoring tests. Friction power taken from differences of indicator measurements, and brake measurements gives then the purely mechanical losses while the friction power taken from motoring tests involves a lower mechanical loss, in so far as the lesser loads produce lower friction, and also includes the lost work that results from piston leakage on the compression and expansion strokes. Brief theoretical consideration of the influence of change in compression ratio on the components of friction discussed indicates that the order of the change of friction with change in compression ratio from indicator and brake measurements may be the same as that obtained from motoring measurements.

The relation between the friction losses of an engine as determined by motoring test and its friction when developing power can be determined by tests in which accurate indicator diagrams are taken. Tests have been made by the Air Ministry of Great Britain (Reference 2) for the purpose of investigating the relation between friction power losses as measured by motoring tests and those obtained by taking differences between indicator and brake power measurements. These Air Ministry tests were made at only one compression ratio and show the effect of the character of the combustion upon friction determinations by the two methods. At high loads and with a retarded spark the two methods gave similar results; with normal spark the motoring method gave results 15 to 20 per cent lower than the indicator method, and for advanced spark the difference was increased to 20 to 45 per cent.

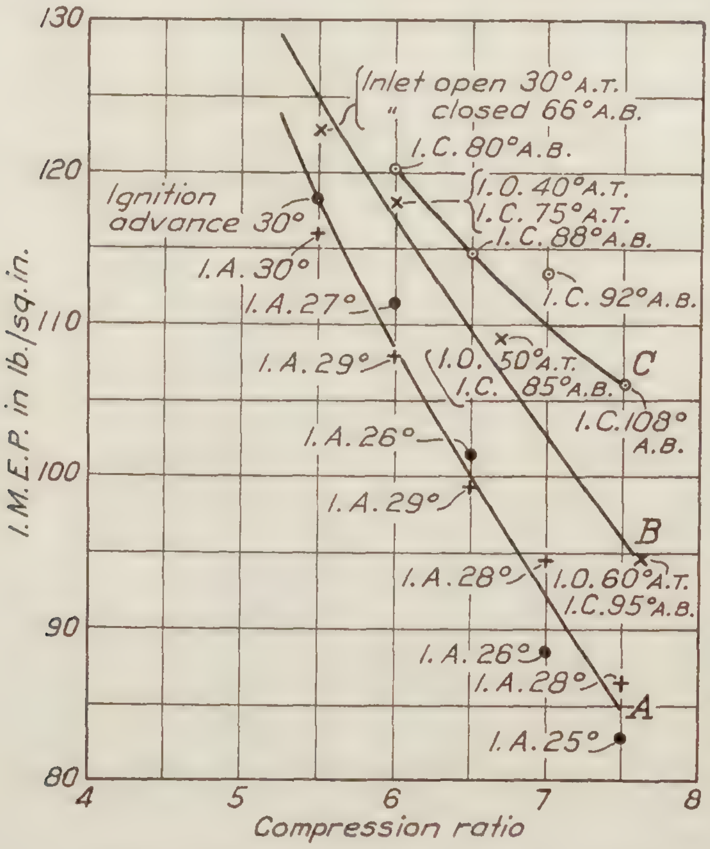


FIG. 11.—Effect of change in compression ratio upon I. M. E. P. when audible detonation is limited by closing throttle or changing inlet valve timing

Motoring power is used as friction horsepower in nearly all test work so that the results obtained with this universal engine and presented herewith are of interest and may apply for certain kinds of combustion. The order of the change in friction for the range in compression ratio investigated in these tests is such that future considerations of engines having compression ratios much higher than used in present engines would make it desirable to make comparisons at a number of compression ratios like those made at a single compression ratio by the Air Ministry.

INLET VALVE TIMING AND THE HIGH COMPRESSION ENGINE

Figure 11 gives indicated mean effective pressures that were obtained at various compression ratios using aviation gasoline for fuel and limiting the detonation at the higher ratios to that considered permissible for continuous operation at a low ratio. These results are presented here as an illustration of the manner in which the variable valve timing mechansim proves valuable in engine research.

Results were obtained for three different methods of limiting detonation: Throttling (curve A), retarding the opening and closing times of the inlet valve (curve B), retarding the closing time only of the inlet valve (curve C). With each method the control was set so that the spark could be advanced beyond the point where maximum power was obtained without causing a perceptible increase in detonation.

These three methods provide different means for controlling the overcompressed engine so that it will not detonate at sea level when using aviation gasoline. When using the first method, the throttle would be opened as the altitude of operation is increased. With the second method, the whole inlet valve timing would be advanced as the altitude is increased.

With the third method only the inlet valve closing time would be advanced as the altitude is increased. The first method has been used considerably, but from these tests it is seen to give the least power at ground level. Figure 11 shows that the second method gives better results than the first. The third method gives the greatest power at ground level, but involves greatest complication of control. Regardless of which method is employed, the same power can be obtained at and above that altitude at which the throttle may be opened wide for the case where it is used to limit detonation and at which the valve timing will be the same as in the throttling case, for the two cases where valve timing is used to limit detonation. A method of limiting detonation by changing the valve timing has been used in the Bristol Jupiter engine and good results have been obtained.

Both the second and third methods are the same in effect in that the delay in closing the inlet valve results in some of the charge drawn in the cylinder being returned to the inlet manifold and the effective compression stroke reduced. Engines so constructed would have, in effect, a lower compression ratio than expansion ratio at low altitudes. The first method involves a similar reduction in volumetric efficiency, but since the compression ratio has not been changed the ratio of the temperatures at the beginning and end of the compression stroke and the compression temperature will be higher, requiring somewhat greater reduction in volumetric efficiency to limit the detonation to the same extent. The ratios of residual gases retained in the cylinder to fresh charge are probably different in the three cases and the difference in power noted is due to this condition to some extent. The first method also involves higher pumping losses than the third.

CONCLUSIONS

The test results presented in this report serve as examples of the use of this universal engine in some research problems where the variable features are of especial service. Examination of the data used in determining the effect of compression ratio on volumetric efficiency together with consideration of conflicting results obtained elsewhere indicate that no general conclusion should be drawn as to the effect of compression ratio on volumetric efficiency. It is evident, however, that an increase in compression ratio from 5 to 13 causes an appreciable increase in friction horsepower as measured by motoring tests.

This engine lends itself to the direct study of such variables. Further study of friction losses from indicator diagrams would determine the relation between the actual losses and those obtained by motoring tests for definite conditions.

REFERENCES AND BIBLIOGRAPHY

Reference 1. Ricardo, H. R.—The Internal Combustion Engine. 1923, 2 vols. London: Blackie & Co.

Reference 2. Moss, H., & Stern, W. J.—The Mechanical Efficiency of an Internal Combustion Engine. Auto. Eng. (London), 1925. XV, 78–82. Figs. 1–10.

Gibson, A. H.—Aero Engine Efficiencies. 36 pp, 13 figs. London: The Royal Aeronautical Society.

Sparrow, S. W.—The Effect of Changes in Compression Ratio Upon Engine Performance. N. A. C. A. Report No. 205, 1925, 22 pp., 25 figs.

REPORT No. 251

APPROXIMATIONS FOR COLUMN EFFECT IN AIRPLANE WING SPARS

By EDWARD P. WARNER and MAC SHORT
Massachusetts Institute of Technology

REPORT No. 251

APPROXIMATIONS FOR COLUMN EFFECT IN AIRPLANE WING SPARS

By Edward P. Warner and Mac Short

SUMMARY

The significance attaching to "column effect" in airplane wing spars has been increasingly realized with the passage of time, but exact computations of the corrections to bending moment curves resulting from the existence of end loads are frequently omitted because of the additional labor involved in an analysis by rigorously correct methods. The present report, prepared for publication by the National Advisory Committee for Aeronautics, represents an attempt to provide for approximate column effect corrections that can be graphically or otherwise expressed so as to be applied with a minimum of labor. Curves are plotted giving approximate values of the correction factors for single and two bay trusses of varying proportions and with various relationships between axial and lateral loads. It is further shown from an analysis of those curves that rough but useful approximations can be obtained from Perry's formula for corrected bending moment, with the assumed distance between points of inflection arbitrarily modified in accordance with rules given in the report.

The discussion of general rules of variation of bending stress with axial load is accompanied by a study of the best distribution of the points of support along a spar for various conditions of loading.

GENERAL NATURE OF PROBLEM

The vital significance of column effect in a slender beam carrying both lateral load and compression has long been realized, and formulæ for dealing with the case of the laterally loaded strut and calculating the equivalent bending moment at various points of such a member have been available for many decades. In civil and mechanical engineering structures, however, the occurrence of beams stressed in flexure and carrying also a compressive load approximating to the "Euler load," or that which would cause failure by lateral instability with lateral load entirely lacking, is rare. Only with the coming of the airplane did the use of members working under such conditions become a commonplace of design, and only then did the need for accurate and complete means of calculating them become acute.

The first efforts to treat "column effect," or the modification of the bending moment diagram by the amount of compression moments dependent on deflection were made through approximations, of which a great number have been devised. One or more are given in every work on the strength of materials, and Newell lists (Reference 1) eight approximate formulæ, all intended to serve the same purpose and giving widely varying results in some cases. Not until 1916 did a complete and rigorously accurate method of calculation of continuous beams under combined load become available. (Reference 2.)

With the development of the "Berry Method" or "Exact Method" or "Generalized Theorem of Three Moments," as it is variously called, the problem of column effect passes into a new stage. Accurate calculations could be made, subject to the usual assumptions about homogeneity of material and the absence of discontinuities of section, and the question then became one of whether or not it was worth while to go through with the somewhat elaborate processes involved in any particular case. In many instances it is not worth while, or is not considered by the designer to be so, and although the generalized equation has had a steadily increasing use in practice its employment is still far from universal.

Taking all this into account, the desirability of having some reliable means of approximating the column effect in advance is obvious. Such a trustworthy means, if one can be secured, will show in some cases that column effect is unimportant and that no check calculations including allowance for it are necessary, while in those instances where it is of importance the inclusion of a preliminary allowance for its magnitude will decrease the liability of having to make two or more tentative spar designs with a calculation for each one.

The difficulty of making exact calculations is not only inherent in the form of the equations, which require for their solution perhaps triple the time needed for the analysis of a continuous beam by ordinary methods, especially in view of the fact that some of the results from the generalized form come out as the relatively small difference of two very large quantities and the number of significant figures that have to be preserved through the preliminary operations is therefore greater than would be necessary for a corresponding degree of accuracy if the equation were left in its familiar form. The labor of a solution is further increased by the fact that the generalized method is only a check, which can not be applied until a preliminary design of the spar section has been made. It is necessary to work the problem through once in order to arrive at that preliminary design and then to work it through again to be sure that the preliminary selection would fit the requirements. Furthermore, in case the check shows the section first chosen to be inadequate or overstrong still another complete set of calculations must be made after the redesign.

The stresses in an airplane wing spar depend on certain properties of the spar section, the wing truss form, and the loading, and for any given general form of truss the number of such properties exerting an influence is definite and small. In a two-bay truss with the spars continuous over three points of support and hinged at their inner ends, for example, the bending and direct stresses depend on the length of each of the three bays of the spar, on the moment of inertia, section modulus, and area of its cross-section, and on the lateral load per unit of length and on the compressive or tensile load applied. The compressive load, however, is itself dependent only on the lateral load, the distribution of supports along the spar, and the gap (if it be a biplane that is under consideration), and the variation of stress with change of linear dimensions in a truss in which geometric similarity is preserved, follows simple and well understood laws. The number of variables can therefore be materially reduced if all factors involving linear dimensions are converted to a constant overall length of spar as a basis of comparison, and coefficients of bending moment figured without regard to column effect can be plotted, for example, in terms of the percentage of total length of spar in the inner bay and the percentage in the overhang as the only two independent variables. Since the inner bay, outer bay, and overhang sum to 100 per cent, any other pair from among those three might be selected instead of the inner bay and overhang as the basic quantities governing the magnitude of the bending moment coefficients.

A complete solution without column effect has been made and published for two-bay wing trusses of proportions extending over the full range of probable design practice. (Reference 3.) It is only a little more difficult to do the same thing with column effect taken into account, and the work has been carried through for two typical wing truss forms, the single bay with overhang and the two-bay truss treated in Technical Report No. 214 (Reference 3), the bending moment at the inner end of the spar being assumed zero in all cases.

SINGLE-BAY TRUSS

When a spar is continuous over only two supports and is pinned at the inner end, the bending moments at the support are obviously independent of any column action, that at the inner end being zero while that at the strut is governed only by the length and loading of the overhanging portion of the spar. The distribution of moment in the bay, however, is directly affected by the compression column moments of magnitude Py, where y is the deflection of the spar after all loads are on it, having to be added to or subtracted from the moments due to lateral load, the sign of the correction of course depending on the signs of the lateral load moment and of the deflection. In general, it is expected that the correction to be applied to the maximum value of the moment in the middle of a bay will be positive, as a spar running over only two supports commonly deflects in the direction of the lateral load, and that gives an additive column correction. It will, in fact, always do so unless the ratio of length of overhang to length of bay is exceptionally great.

The formula for the maximum value of a bending moment attained between supports is given by Berry as:

$$M_{max.}=\frac{w}{\mu^2}-\left(\frac{w}{\mu^2}-\frac{M_A+M_B}{2}\right)\sec \mu x \sec \alpha$$

where x is the distance from the point of maximum moment to the middle point of the bay, and is in turn defined by:

$$\tan \mu x=\frac{M_A-M_B}{M_A+M_B-\frac{2w}{\mu^2}}\cot \alpha$$

and the other symbols are:

P = compressive load
E = modulus of elasticity of material
I = moment of inertia of cross section
w = lateral load per unit length of spar
$\mu=\sqrt{\frac{P}{EI}}$
l = length of bay of spar
$a=\frac{l}{2}$
M_A and M_B = moments at ends of bay
$\alpha=a\mu=\frac{l}{2}\sqrt{\frac{P}{EI}}$.

In the particular case under consideration M_B is 0, and the form becomes somewhat simplified, being most conveniently expressible for most calculations in the shape:

$$\frac{w}{\mu^2}(1-\sec \mu x \sec \alpha)+\frac{M_A}{2}\sec \mu x \sec \alpha$$

it will be observed in this formula that each term varies as wl^2 if α is kept constant. It is possible to consider ordinary bending moment stress charts, such as were given in Report No. 214 (Reference 3), therefore as representing the special case in which α equals 0° (no compressive load), and similar sets of charts could be developed for any other value of α. For a given value of that quantity, in other words, coefficients of bending moment can always be written independently of the absolute values of the lateral loading, the dimensions of the truss, and the dimensions of the spar section, varying only with the distribution of the struts along the spar, or in this particular case with the placing of the single strut.

The calculation has been made for five cases, with the length of the effective overhang 22.2, 30, 35, 37.5, and 40 per cent of the total effective overall length, the true length having been reduced for the tip loss allowance. The bending moment at the strut, all results being reduced to a total spar length of 100 inches and to a loading of 1 pound per inch of length, would then be 246, 450, 612, 703, and 800 pounds inches in the five cases, while the maximum bending moment in the bay with no column effect would on similar assumptions be 638, 408 266, 200, and 139 pounds inches.

Making similar calculations of moment in the bay for the five cases with various values of α ranging from 15° to 85°, the values found to change are tabulated below and plotted in Figure 1.

The statement of α as an angle is of course a mathematical fiction. It is actually a pure number, which becomes equal to $\pi/2$ when the point of collapse as a column is reached, but since the development of the theory brings in certain terms which can be best expressed by trigonometric functions, it is sometimes convenient to state the variable as an angle. The direct solution, $\alpha=\frac{l}{2}\sqrt{\frac{P}{EI}}$, of course gives the angle in radians.

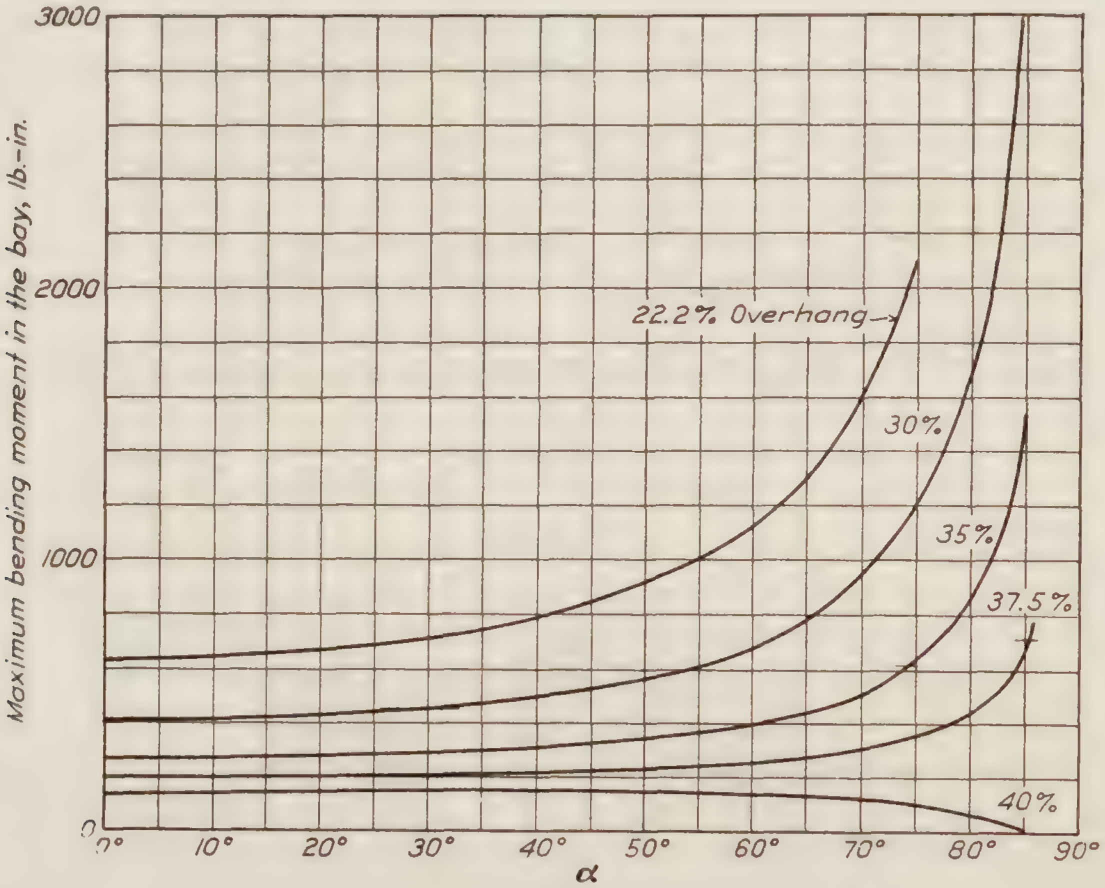


FIG. 1

	Moments in bay					Moment in bay / Moment without column effect				
	Per cent length of overhang									
	22.2	30	35	37.5	40	22.2	30	35	37.5	40
0°	638	408	266	200	139	1.00	1.00	1.00	1.00	1.00
15°	653	416	270	----------	140	1.02	1.02	1.02	----------	1.01
30	710	446	288	211	141	1.11	1.09	1.08	1.06	1.01
45	843	530	323	----------	142	1.32	1.30	1.22	----------	1.02
60	1,124	680	397	261	139	1.76	1.67	1.49	1.31	1.00
75	2,090	1,196	623	----------	112	3.28	2.93	2.34	----------	.81
80	----------	1,706	850	431	78	----------	4.18	3.20	2.16	.56
85	----------	3,254	1,536	671	6	----------	7.98	5.77	3.36	.04

As the computations in making up this table were never carried beyond four significant figures, the last digit in the moment figures is somewhat uncertain but the probable error is not in excess of 1%.

In Figure 1 the moments are plotted directly, while Figure 2 shows the ratios of correction factor required by column effect. It will be observed that there is comparatively little difference among the first four curves in Figure 2, suggesting the possibility of using a standard curve of the correction factor to be applied to moments in the middle of the bay, and the value of α for all single bay wing trusses with overhang lengths of less than 37 per cent provided α does not exceed about 45°. Figure 3 is plotted with the same ordinates as Figure 2, but with the abscissæ changed to the ratio $\frac{P}{P_e}$, where P_e is the Euler load, $\frac{\pi^2 EI}{l^2}$. This ratio is equal to $\left(\frac{\alpha}{90}\right)^2$.

In Figure 1, on the curves corresponding to the 30, 35, and 37.5 per cent, overhangs the value of the moment at the strut has been indicated by a short cross line. Even with an overhang as long as 37.5 per cent, approaching a semicantilever form, the moment in the bay supersedes that at the strut as the critical element in the calculation when the end load is more than 90 per cent of that under which the spar would collapse as a simple column pin-jointed at its ends.

While it would be possible, as just noted, to plot a single curve of moment correction factors for single-bay trusses which would hold within a maximum error of 10 per cent or 15 per cent for all cases likely to be met with in practice, except those with overhangs so long that they would ordinarily be described and thought of as semicantilever types, it would be better either to continue the use of several such curves as those in Figure 3 and to interpolate for the particular length of overhang under consideration, or, alternatively, to find some general approximate method, either emperical or rational, which comes sufficiently close to fitting all cases.

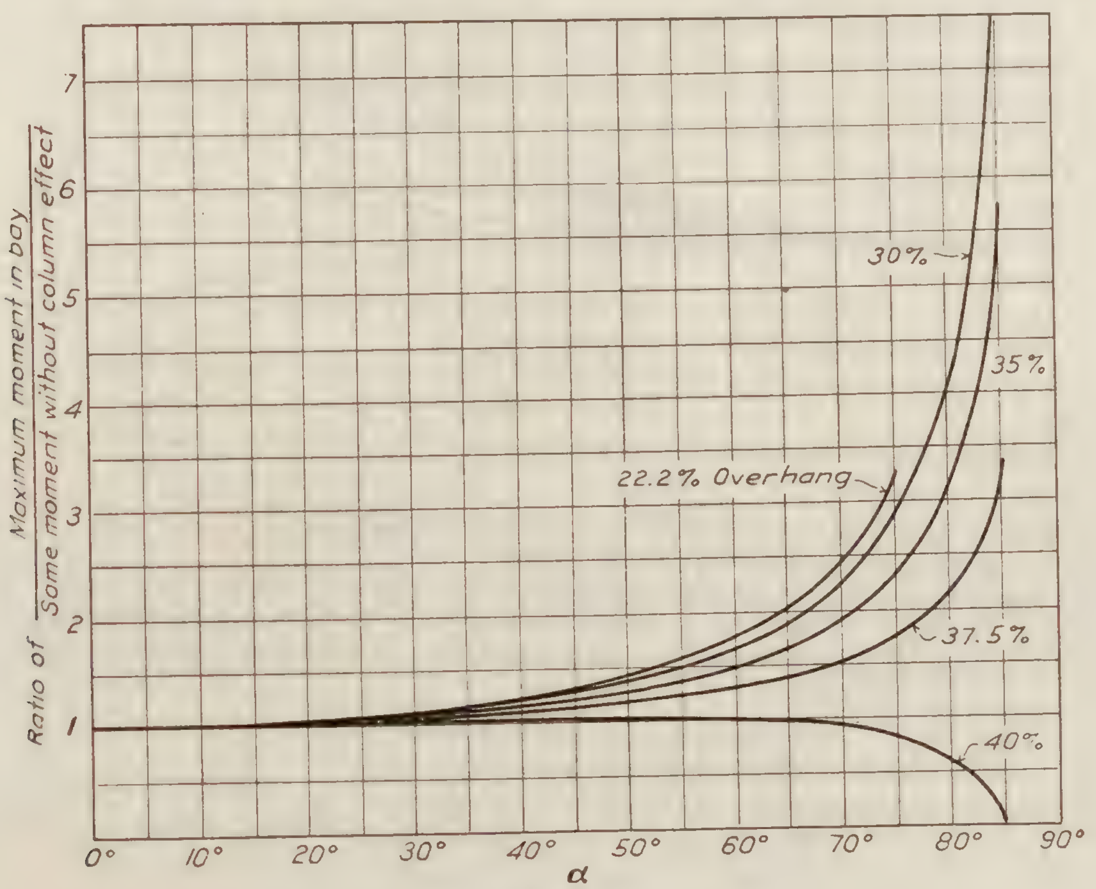


FIG. 2

An approximation much used in such cases is the Perry formula. (Reference 4.)

$$M' = \frac{M \times P_e}{P_e - P}$$

where P is the end load actually carried, P_e the Euler load, M the moment under lateral load alone, and M' the moment with allowance for column effect. Since the formula was devised for application to struts carrying a lateral load and pin-jointed at their ends, it is manifestly unfair to allow nothing for stiffening of the spar by continuity past one or both of the ends of the bay, and in actual use the factor P_e is commonly replaced by P_e', equal to $\frac{\pi^2 EI}{l'^2}$, l' is the distance between the points of inflection rather than that between the ends of the bays. That distance itself, of course, varies with the length of overhang, a curve of $\frac{l'}{l}$

for the single-bay spar with hinged inner end being plotted against percentage length of overhang in Figure 4.

Unfortunately, the points of inflection do not remain fixed, but move outward toward the ends of the bay as the column effect becomes increasingly important. The writer has made it a practice to allow for this shift empirically by basing the Euler load in the Perry formula neither on l nor l', but on a fictitious length $l'+n(l-l')$. The coefficient n is, of course, fractional and varies with the type of truss under consideration. For the single-bay truss with the spar pin-jointed at the inner end experience shows that a value of 0.8 for n gives best results.

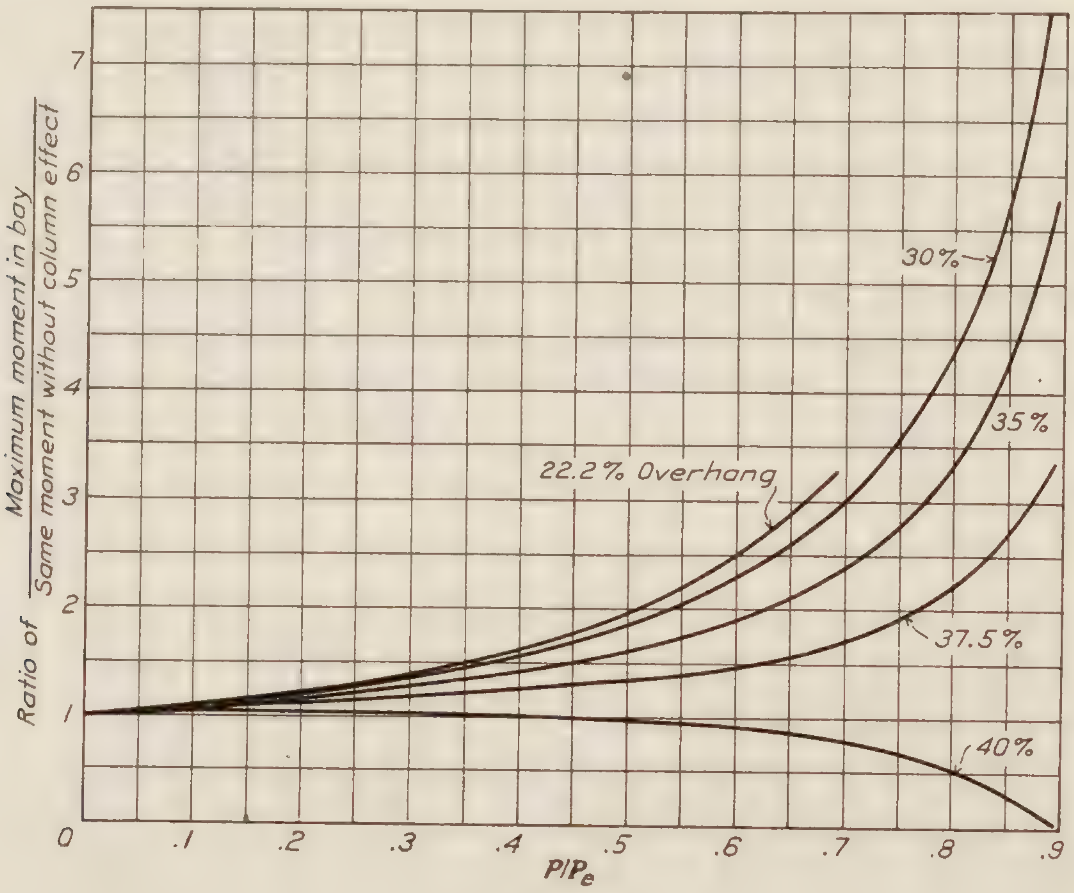


FIG. 3

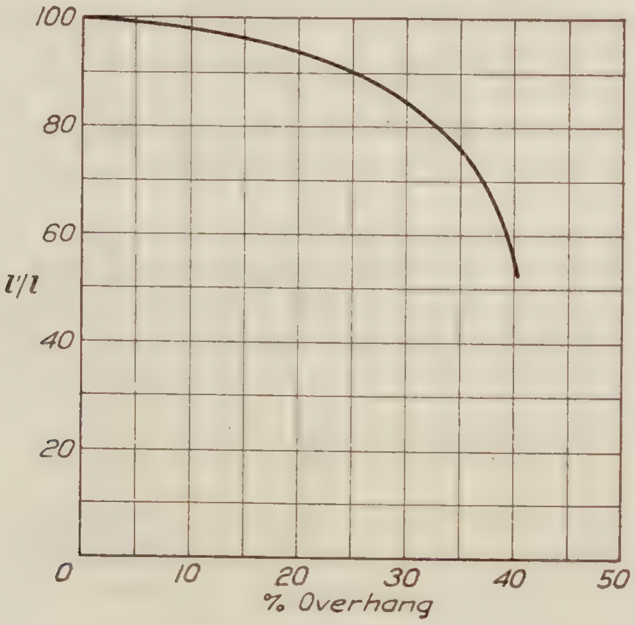


FIG. 4

The Perry formula correction factors have been calculated on that basis, and the ratio of the correct maximum bending moment in the bay to that approximately determined by the formula is plotted in Figure 5. The 40 per cent overhang has been omitted in both cases, as it is manifest that no correction factor is needed in that case, and any factor or method which increases the value of the moment will be worse than none at all.

It is evident that the Perry formula gives excellent results in general. The values for the maximum moment derived by its use are correct within 5 per cent for all values of α up to 68° with a 22 per cent overhang, 76° with 30 per cent, 44° with 35 per cent, and 32° with 37.5 per cent. Most of the cases met with in practice will show values of α lower than these, and it can therefore be said in general that the Perry formula gives approximations sufficiently accurate for ordinary use without any exact calculation except when the overhang is unusually long and the compression in the bay large. Exact figures can be read off, of course, by interpolation between the curves in Figure 3 if that is desired.

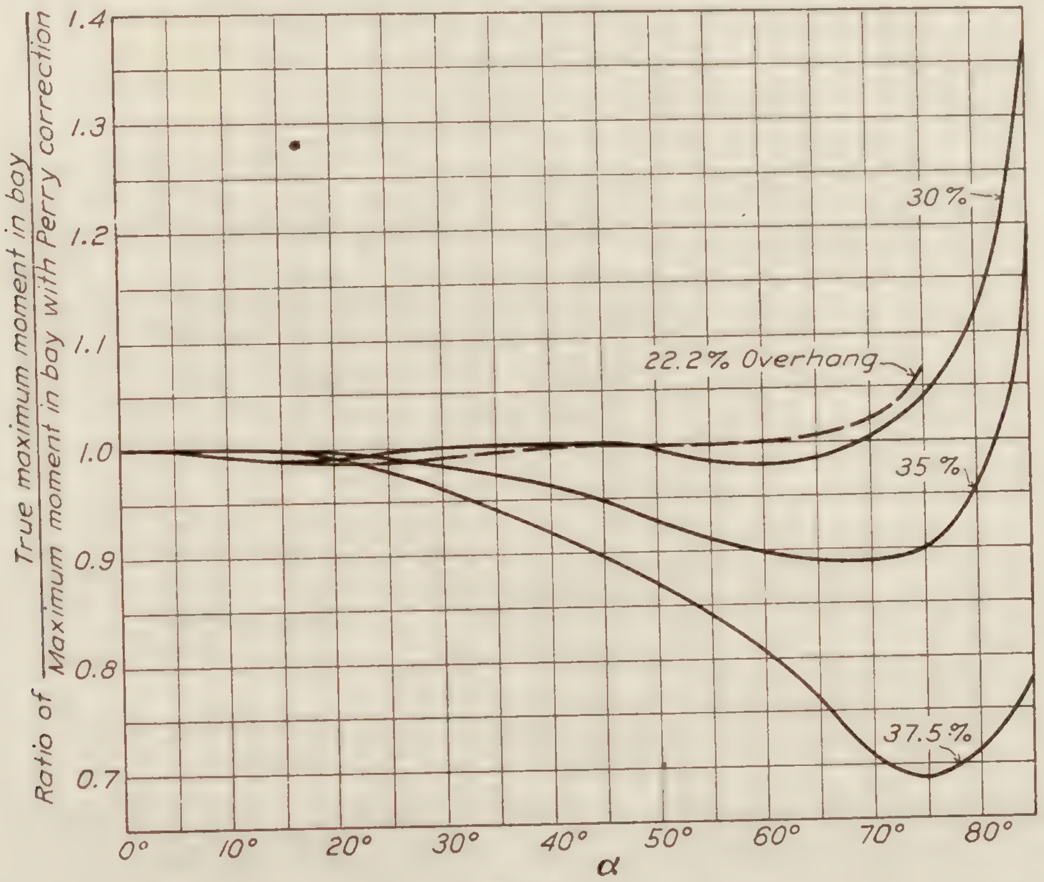


FIG. 5

The sudden change of form of the curve of variation of maximum bending moments with compression in the bay in going from a 37.5 to 40 per cent overhang is startling at first sight. It is, however, entirely logical, and it would be expected that there would be a very sharp, if not absolutely discontinuous, passage from beams in which the moment increases very rapidly at large values of α to those in which it decreases with corresponding rapidity in the same region. The reason is that when α approaches very closely to 90° the compression moments become the controlling factor, and whether those moments act with or against the effect of lateral load in the middle of the bay depends on the form of the initial deflection curve, which, in turn, is governed by the length of overhang. Figure 6 illustrates diagrammatically the general form of deflection curves that would be found with 30 and 40 per cent overhang, respectively, and the variation of the curve with changing α in the two cases. Manifestly, when α is

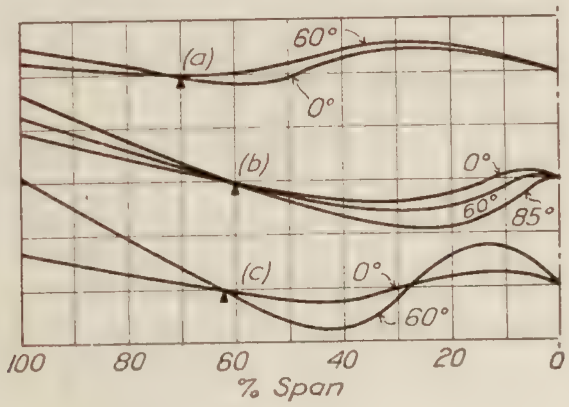


FIG. 6

very large it is almost certain that either the part of the beam which was initially deflected above the datum line or that which was deflected below will have taken control, and the column moments will have thrown all the deflections in one direction. Such a condition as is indicated in the third diagram in Figure 6 is conceivable, but most unstable and unlikely.

In order to illustrate the amount of work involved in an accurate calculation for one overhang the complete figures for the case of 40 per cent overhang are tabulated below:

ILLUSTRATIVE CALCULATION

Length of bay=60″
Length of overhang=40″
w=1 lb./in. M_A=800 lb. in.

α (deg.)	15	30	45	60	75	80	85
α (rad.)	0. 26180	0. 52360	0. 78540	1. 04720	1. 30900	1. 39627	1. 48353
sec α	1. 03528	1. 15470	1. 41421	2. 00000	3. 86371	5. 75877	11. 47380
csc α	3. 86371	2. 00000	1. 41421	1. 15470	1. 03528	1. 01543	1. 00382
$\mu=\left(\frac{\alpha}{30}\right)$	. 008727	. 017453	. 026180	. 034907	. 046542	. 046542	. 049451
$\frac{1}{\mu^2}$	13130. 2	3282. 92	1459. 02	820. 68	525. 25	461. 65	408. 93
M_A csc α	3090. 97	1600. 00	1131. 37	923. 76	828. 22	812. 34	803. 06
M_A sec α	828. 22	923. 76	1131. 37	1600. 00	3090. 97	4607. 02	9179. 00
$\left(\frac{1}{\mu^2}-\frac{M_A}{2}\right)\sec\alpha=(A)$	13179. 2	3328. 90	1497. 68	841. 36	483. 95	355. 01	102. 46
$\frac{M_A \csc\alpha}{2\sec\left(\frac{1}{\mu^2}-\frac{M_A}{2}\right)}=(\tan\mu x)$	. 11724	. 2403	. 3777	. 5489	. 8556	1. 1442	3. 919
μx (deg.)	6° 41′	13° 31′	20° 41′	28° 46′	40° 33′	48° 51′	75° 41′
μx (rad.)	. 1167	. 2359	. 3610	. 5020	. 7078	. 8526	1. 3209
x	13. 37	13. 52	13. 79	14. 38	16. 22	18. 32	26. 71
sec μx	1. 0069	1. 0285	1. 0689	1. 1407	1. 3160	1. 5196	4. 0450
sec μx sec α	1. 0424	1. 1875	1. 5117	2. 2814			
$M_{max.}=\left((A)\ (\sec\mu x)-\frac{1}{\mu^2}\right)$	139. 7	140. 9	141. 8	139. 0	111. 6	77. 8	5. 5

LOCATION OF STRUT

The most economical strut location in a single-bay truss with untapered wing spars, considering only spar weight, is obviously that which makes the moment at the strut equal to the maximum in the bay. The percentage length of overhang to be used to conform with that specification is plotted against α in Figure 7, and it will be observed that the variation in strut location with change of α is very slow. To determine the exact value for any particular case α should be found in terms of other and more general properties of the airplane.

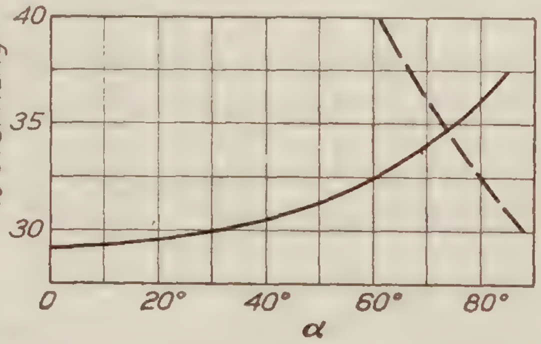


FIG. 7

In the particular, and very common, case of the biplane with upper and lower wings of equal size, and with the loading on the lower wing assumed to be 90 per cent of that on the upper, the compression in the upper spar is independent of strut location, and is always:

$$P=\frac{1.9\ Wl^2}{2G}=\frac{Wl^2}{1.05G}$$

where P is the compression, w the load on the spar in pounds per unit of length, l the total effective length of the spar (with the correction for tip loss taken off), and G the gap. The moment of inertia of the spar by the familiar formula for bending stress is equal to:

$$I=\frac{Mc}{f_b}$$

c being the distance from the neutral axis to the outermost fiber. On the assumption that the bending moment in the bay is to be equal to that at the strut and that the latter can therefore be taken as one of the worst conditions, I becomes for a symmetrical spar:

$$\frac{wdl_o^2}{4f_b}$$

l_o being the length of the overhang and d the depth of the spar. Then, l_b being the length of the bay,

$$\frac{P}{EI}=\left(\frac{l}{l_o}\right)^2\times\frac{3.8f_b}{GdE}$$

$$\alpha=\frac{l_b}{2}\sqrt{\frac{P}{EI}}=\sqrt{\frac{l^2{}_b\,l^2}{l_o^2}\times\frac{f_b}{1.05GdE}}=\sqrt{\frac{l_b}{l_o}\frac{f_b}{E}\frac{l^2}{1.05Gd}}$$

f_b can be determined in terms of the ultimate total stress.

$$\frac{f_b}{f_t}=\frac{\frac{Mc}{I}}{\frac{Mc}{I}+\frac{P}{A}}$$

On the assumption, previously discussed elsewhere (Reference 5) that the radius of gyration of an airplane wing spar section is 0.36 of the depth,

$$\frac{c}{I}=\frac{1}{.26dA}$$

$$M=\frac{wl_o^2}{2} \qquad P=\frac{wl^2}{1.05G}$$

$$\frac{f_b}{f_t}=\frac{1}{1+.48\frac{d}{G}\left(\frac{l}{l_o}\right)^2}$$

The product of $\frac{d}{G}$ and $\left(\frac{l}{l_o}\right)^2$ practically always lies between 0.64 and 1.33, corresponding to a range of $\frac{f_b}{f_t}$ of from 0.61 to 0.78. Either in spruce or in duralumin, $\frac{f_b}{E}$ will then be between $\frac{1}{285}$ and $\frac{1}{340}$, with the smaller values going with a short overhang.

Taking the factors entering into the expression for α separately, $\frac{l_b}{l_o}$ may vary 1.5 to 3.0, $\frac{l}{G}$ from 2.2 to 4.6, and $\frac{l}{d}$ from about 25 to 53. For any particular values of those quantities α can be calculated from the formula, and the value so found should be equal to that which makes the moments at the strut and in the bay equal for the overhang length under consideration.

The method of determining optimum overhang can best be demonstrated by a particular problem. $\frac{l}{G}$ will be taken as 3.5, $\frac{l}{d}$ as 40, and a series of overhang lengths tried.

$\frac{l_o}{l}$	$\frac{l_b}{l_o}$	$\frac{f_b}{f_t}$	$\frac{f_b}{E}$	α (rad.)	α(deg.)
.30	2.33	.682	$\frac{1}{305}$	1.54	88°
.35	1.86	.745	$\frac{1}{279}$	1.28	73°
.40	1.50	.793	$\frac{1}{262}$	1.07	61°

These points have been plotted in the dotted line in Figure 7, and the intersection of the two curves defines the best effective overhang at just under 35 per cent (equivalent, with the usual deduction of one-fifth or one-sixth of a chord length from the end to allow for tip losses, to about 40 per cent true overhang).

The solution of other problems of a similar nature gives the data for Figure 8, where curves are plotted to show the best length of overhang in terms of $\frac{l}{d}$ and $\frac{l}{G}$. The extreme range of useful values, it will be noted, is from 31 to 39 per cent.

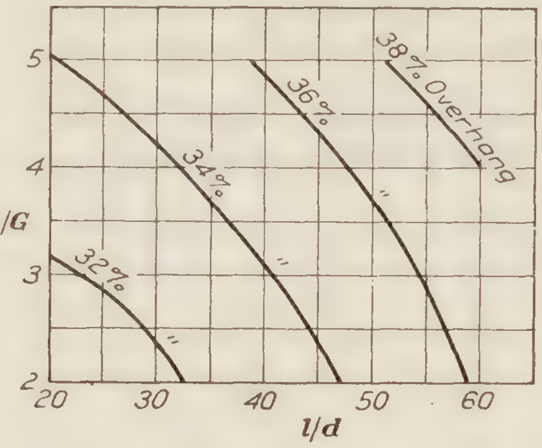


FIG. 8

TWO-BAY TRUSSES

The same general method can be used for investigating the magnitude of column effect in wing spars continuous over three supports, although of course the number of variables steadily increases with increasing number of bays. Such a study has been made for a particular case of the two-bay spar pin-jointed at its inner end.

The trusses selected for calculation in this case have the proportions listed below:

No.	Length inner bay	Outer bay	Overhang
	Per cent	*Per cent*	*Per cent*
I	32.5	45	22.5
II	29.5	54.6	15.9
III	33.3	38.5	28.2
IV	37.1	42.9	20
V	27.1	50	22.9
VI	40	45	15
VII	35	45	20
VIII	30	45	25
IX	40	50	10
X	31.7	48.3	20

The calculations for the first case, and for the first alone, were carried through completely for seven different values of α ranging from 15° to 85°. The general form of the curve of variation of moments with changing compression in the spar having thus been determined, only a few values were selected for each of the other cases. The inner and outer bays of course have different values of α. The larger of the two values was in every case used as a key number for indexing. In other words, when α is mentioned in a tabulation or plot it is, unless otherwise specified, taken from the bay having the largest α. That is true even when the specific quantity tabulated or plotted in terms of α relates directly to the other bay, the one with the smaller α. In most two-bay spars α is larger in the inner bay than in the outer, and it is therefore in the inner bay that the column effect is most critical, but if for any reason the ratio of length of outer bay to inner is made especially great that condition is changed, and it is between the inner and outer struts that the spar comes nearest to failure as a simple column. Among the cases here discussed, α was greater in the outer bay than in the inner only in Nos. II, V, and VIII.

A beam continuous over three supports and pinned at the inner end of course has a zero bending moment at that point, and the moment at the other end support, corresponding to the outer strut, is dependent only upon the properties of the overhanging portion and not on the compression in the bays. The moment at the middle support, however, varies with the compression—a fact which is not taken into account by any of the ordinary approximations for column action. It is manifest that in general the bending moment at the intermediate support of such a beam will be increased by compression in the bays, as the general direction of the deflection is the same as that of the lateral load, and the application of compressive force tends therefore to spring the mid-point of the beam up away from its restraint at the support with increased force. The reaction at the middle support is therefore increased and the bending moment must increase in absolute value likewise.

The way in which the magnitude of any increase depends on α and on the distribution of the supports of the spar is best shown by tabulation and plotting of particular examples. The values of M_B ($_B$ being the middle support) for the nine cases previously described are tabulated below, while curves of M_B against α are plotted for five of them in Figure 9.

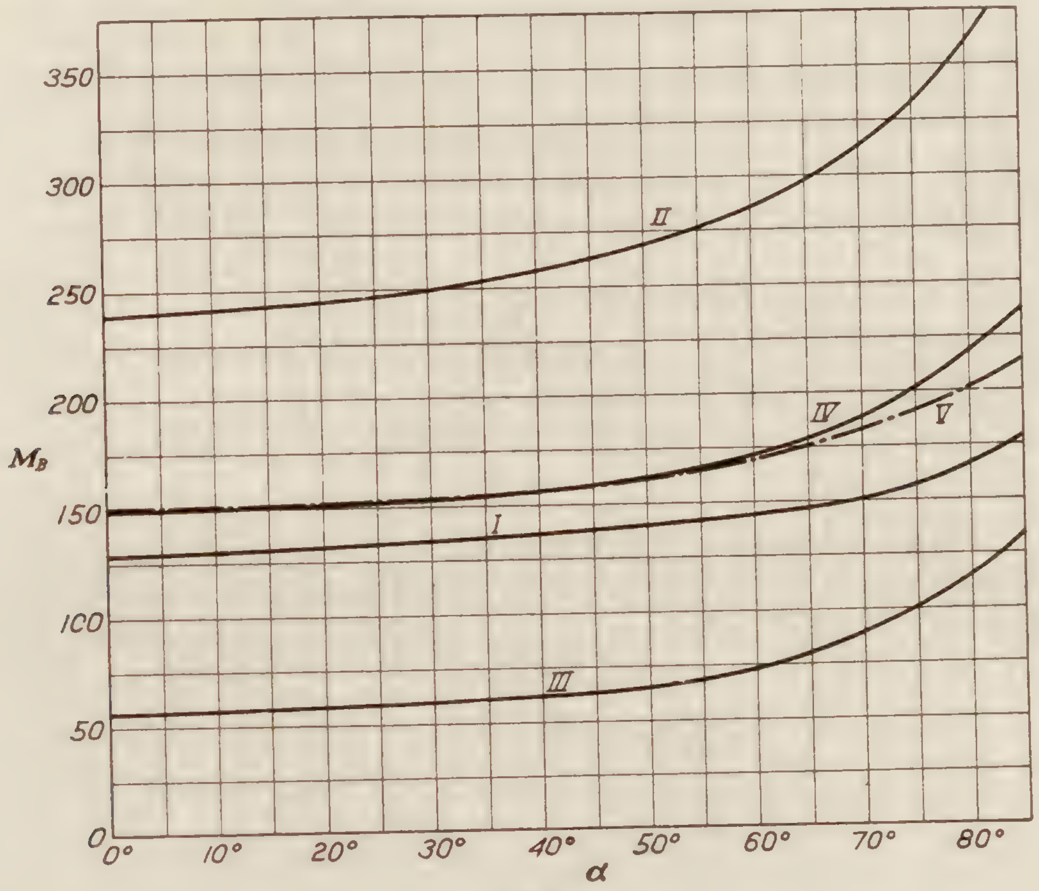


FIG. 9

No.	α							
	0°	15°	30°	45°	60°	75°	80°	85°
I	129	130	132	137	145	158	164	179
II	239	-------	248	-------	285	-------	359	-------
III	57	-------	59	-------	73	-------	115	-------
IV	149	-------	154	-------	172	-------	218	-------
V	150	-------	154	-------	170	-------	201	-------
VI	198	-------	-------	-------	224	-------	-------	-------
VII	153	-------	-------	-------	173	-------	-------	-------
VIII	97	-------	-------	-------	111	-------	-------	-------
IX	248	-------	-------	-------	273	-------	-------	-------

Figure 9 having shown the variation of the absolute values of the moment, Figure 10 represents relative variation for ratio of the moments of middle support for various values of α to the corresponding figure with α equal to zero (column effect absent). The curves are plotted against α and each one represents one of the typical cases calculated.

To correlate these results and make it possible to predict probable values of M_B as far as the proportions are different from these here tried, a contour chart was constructed with curves representing equal values of the relative column effect or percentage correction to M_B at a given α. The form of the chart showed that the correction factors were substantially a factor of the percentage length of the outer bay, varying through a range of only 3 or 4 per cent with varying distribution of the remaining spar length between the inner bay and the overhang. Curves of correction factor to be applied to M_B for various values of α have therefore been plotted against the length of outer bay in Figure 11. They are necessarily somewhat rough in form, being based on such a small number of points, but they should make it possible to estimate M_B with an error not in excess of 5 per cent for any probable strut location as long as α does not exceed 65°. It is not likely to pass that point by much, if at all, with the gap-chord ratios and aspect ratios used in practice.

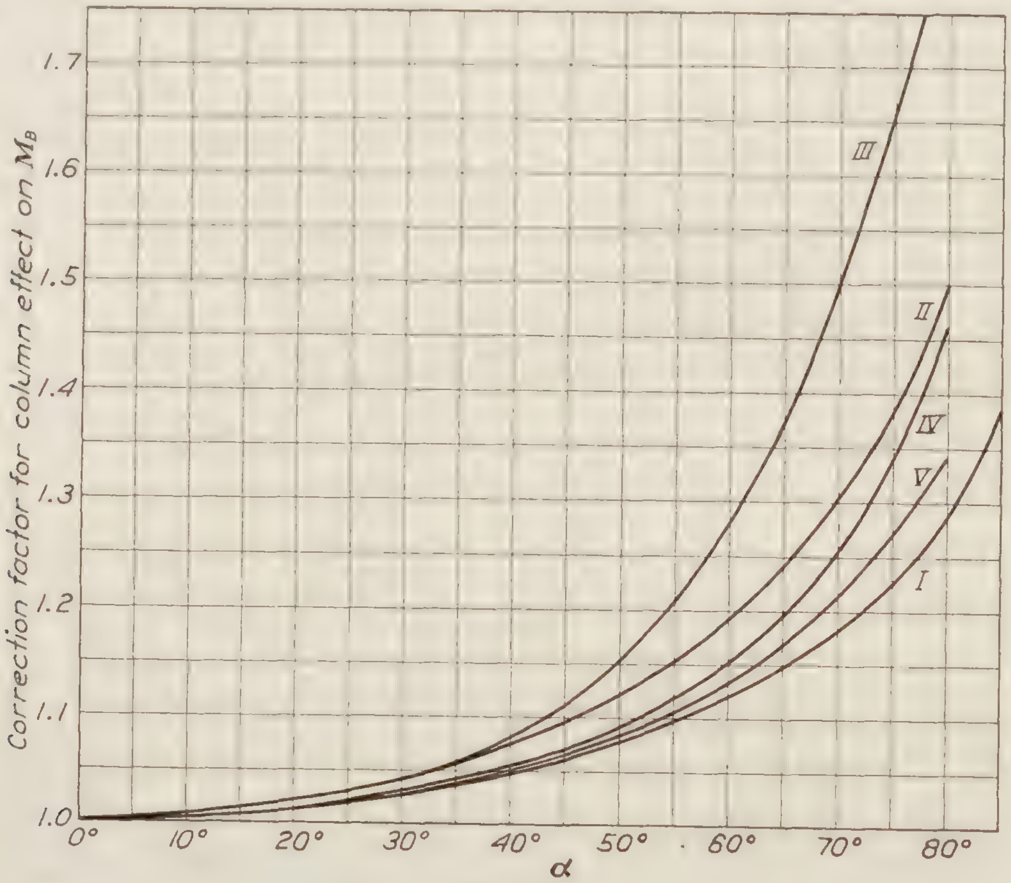


FIG. 10

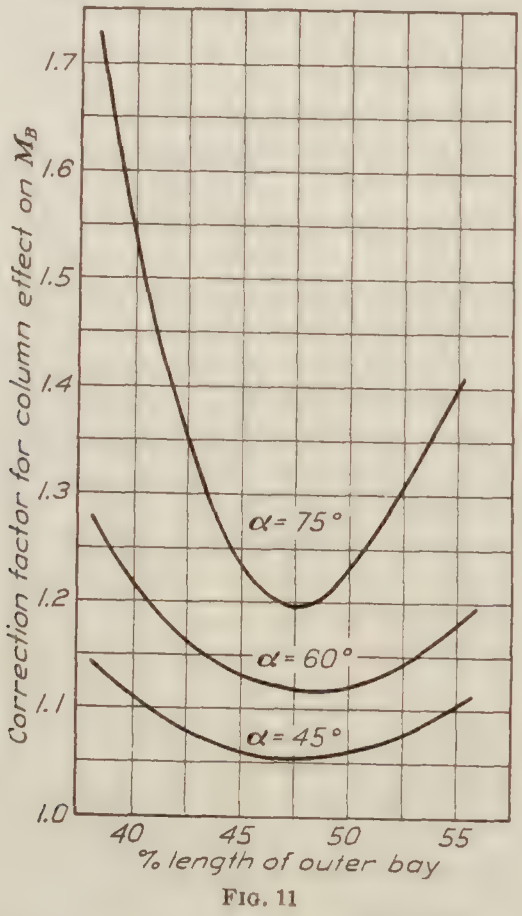


FIG. 11

A preliminary estimate of M_B by the use of these curves serves two purposes. In the first place it will often make it possible to design a spar directly with no explicit calculation by the exact method for the particular dimensions in question. Secondly, it greatly reduces the time that sometimes has to be given to repeated trials to determine the correct section and correct values of α for the outer and inner bays. Manifestly any change of M_B also changes the compression in the outer bay and the value of α in that bay. That makes astonishingly little difference so long as α in the outer bay is smaller than that in the inner bay. An arbitrary reduction of α in the outer bay in Case I by one-third changed the bending at the middle support by less than 2 per cent, so long as α did not exceed 82° in the inner bay. In the general case in which the inner bay is the critical one, recalculation to allow for change in compression in the outer bay is therefore unnecessary, but when the outer bay is the larger value of α those changes become very serious and anything that can be done to facilitate their prediction in advance and without any repeated trials, as these charts facilitate it, tends toward increased accuracy and economy of time.

MOMENTS WITHIN THE BAYS

The maximum values of the moments within the inner and outer bays, as well as those of M_B, the moment at the inner strut, have been calculated directly for a number of illustrative cases, including all except Nos. VI, VIII, and IX of the 10 already tabulated and any additional one, No. XI, introduced to cover the case in which the values of α in the inner and outer bay are very slightly unequal.

As a first step in the systematic treatment of the results of these calculations 60° has been selected as a standard value of α and the figures for the seven strut distributions tried are tabulated herewith for that value. As before, the bay in which α is the largest, whether inner or outer, is always taken as the basis of rating, and the value of α is considered as fixed at 60° in that bay.

Case	Lengths			Bay having largest value of α (α in that bay $=60°$)	Corresponding α in other bay
	Inner bay	Outer bay	Overhang		
					°
I	32.5	45.0	22.5	Inner	54.7
II				Outer	48.5
III				Inner	45.8
IV				do	36.2
V				Outer	46.0
VII	35.0	45.0	20.0	Inner	48.4
X	31.7	48.3	20.0	Identical	60.0
XI	32.5	47.5	20.0	Inner	57.1

Case	$M_{max.}$ in bay where α is largest	$M_{max.}$ in that bay with no column effect	Ratio: $\frac{M_{max.}\ (\alpha=60°)}{M_{max.}\ (\alpha=0°)}$	$M_{max.}$ in other bay	$M_{max.}$ with no column effect	Ratio: $\frac{M_{max.}}{M_{max.}\ (\alpha=0°)}$
I	106	75	1.41	66	66	1.00
II	273	191	1.43	7	23	.30
III	183	119	1.54	−36	−4	
IV	154	104	1.48	45	58	.78
V	140	113	1.25	26	33	.79
VII	119	85	1.40	79	77	1.03
X Inner	62	56	1.10			
X Outer	165	108	1.53			
XI	80	63	1.21	129	91	1.42

The fact most strikingly evidenced by the table is that column effect is always of negligible importance or actually negative in the bay, having the smaller α, unless the two bays are very close together in that respect. The correction factor for the moment in that bay exceeds unity only when the inner strut is within 4 per cent of the length of the spar from the position which would make the two values of α exactly equal.

The explanation is of course essentially the same that served to account for the falling off of mid-bay moments with increasing compression in a single-bay spar with a long overhang. The deflection being largest in that bay in which α is largest, that portion of the spar "takes control" as the compression is increased and forces a steady decrease of the deflection in the other bay. An actual negativing of the column effect and decrease of mid-bay moments in the bay with the smaller α result in many cases. The nature of the effect is graphically shown in Figure 12, where the deflection curves for the spar covered by Case I are plotted for three values of α (in the inner bay). These curves, it should be noted, are not diagrammatic sketches like those of Figure 6, but are the result of actual deflection calculations and accurately represent the change of the form of the elastic curve for a particular spar as the compression varies, the lateral load remaining constant.

The comparatively slight change of the deflection curve with changing α when that quantity is below 60° and the much more rapid change as 90° is approached is strikingly shown, as is the manner in which the inner bay "takes control" when the compression is very large so that the spar is finally forced down below the line of supports everywhere in the outer bay, giving a negative column effect on the moments there, even though the line of the spar continues to show a double reversal of curvature within the bay. Even under the largest end loads the deflections in the bays are small compared with that at the tip of the overhang, which to be sure is unusually long in this particular spar.

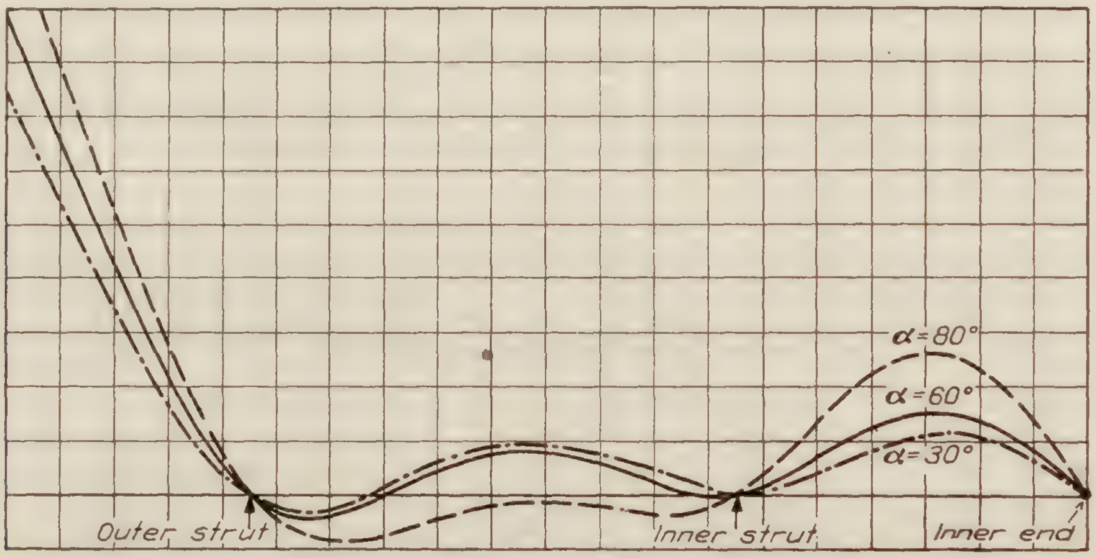


Fig. 12

In the bay where α is largest, and where column effects are therefore uniformly positive, the correction factors on mid-bay moments range from 1.10 to 1.54 in the group of illustrative problems considered. There are hardly enough points to plot a satisfactory contour chart of correction factors in terms of the dimensions of the truss, and therefore the figures can most easily be systematized by relating them to the factors given for corresponding conditions by Perry's approximate formula, exactly as was done in examining the moments in the single-bay spar.

Again the value of n, the coefficient expressive of the proportion of the residual length of the bay by which the points of inflection are to be assumed shifted apart in figuring P_e' for the Perry correction factor, has been determined empirically, and in this case the best figure to use was found to be 0.2 in place of the 0.8 determined for the single bay. It is natural that n should be reduced, since the moments at the ends of the single bay are independent of the compression, while in a two-bay spar the increase of M_B with increasing compression tends to shift the points of inflection closer together and so to neutralize in part the direct effect of the column effect within the bay in relocating those points.

The table below includes the actual correction factors, reproduced from the previous table, the factors calculated by the Perry formula, and the ratio of the two.

Correction factors are to be applied to the maximum moments within the bay in which column effect is greatest when α in that bay is 60°.

Case	Bay considered	True correction factor	Correction factor by Perry formula ($n=.2$)	$\frac{\text{True factor}}{\text{Perry factor}}$
I	Inner	1.41	1.41	1.00
II	Outer	1.43	1.36	1.05
III	Inner	1.54	1.61	.96
IV	Inner	1.48	1.55	.95
V	Outer	1.25	1.26	.99
VII	Inner	1.40	1.40	1.00
X	Inner	1.10	1.32	.83
	Outer	1.53	1.27	1.20
XI	Inner	1.21	1.34	.90

It will be observed that the true and approximate correction factors never differ by more than 6 per cent unless the values of α in the inner and outer bays differ from each other by less than 8 per cent. If α is the same in the two bays, however, the approximation goes badly astray. To show where this critical region of equal α lies the curve in Figure 13 has been drawn, showing the relationship that must exist among the three parts of the length of the spar in order that α may be exactly the same in the two bays.

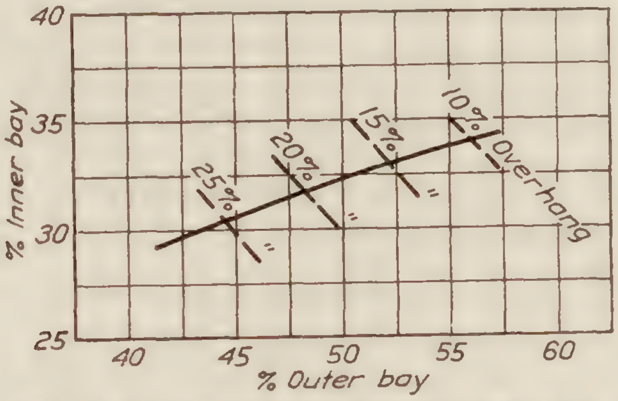


FIG. 13—Proportions of truss for equal α in two bays

All of the conclusions so far drawn, and all of the discussion except that on the deflection curves of Figure 12, have related directly to a single particular value of α. In Case I, for which the deflections were computed and plotted, the maximum moments within both bays were figured for a number of different values of that function, and a few extra moments were figured, too, for Cases II and IV. The results are tabulated below, and the ratios of the moments of the corresponding figures with no compression in the spar are plotted in Figure 14.

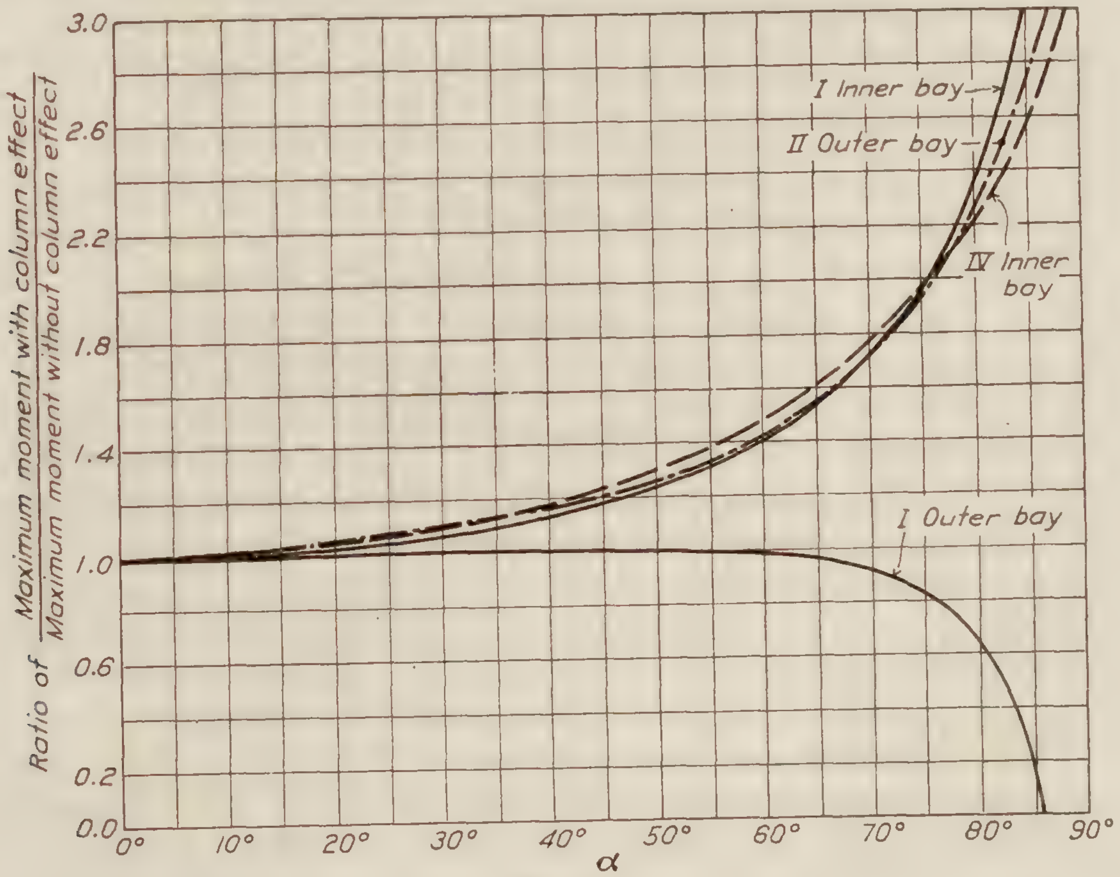


FIG. 14

MOMENTS

α	Inner bay	Outer bay	Outer bay	Inner bay
	Case I	Case I[1]	Case II	Case IV
0°	75	66	191	104
15	76	66		
30	81	67	213	115
45	89	67		
60	106	65	273	154
75	146	55		
80	177	42	432	231

[1] The outer bay having the smaller value of α, these are the outer-bay moments for the condition in which α in the inner bay is as indicated in the left-hand column. In the outer bay it is actually about 10 per cent smaller.

Although there is some crossing back and forth among the curves in Figure 14, all are of the same general type (except, of course, the one which is drawn for a noncritical bay and in which the correction factors drop off below unity). The effect of the change in sign of the deflection in the outer bay in Case I is clearly shown. The column effect is at first positive and almost exactly large enough to balance the effect of the shift of the whole moment curve by virtue of the increasing absolute values of the moment at the inner strut, so that the maximum moment in the bay remains substantially constant over a wide range of values of α. Then, as α is further increased, the spar is forced down to a negative deflection as shown in Figure 12, the column effect becomes negative, and the moment in the bay drops off rapidly.

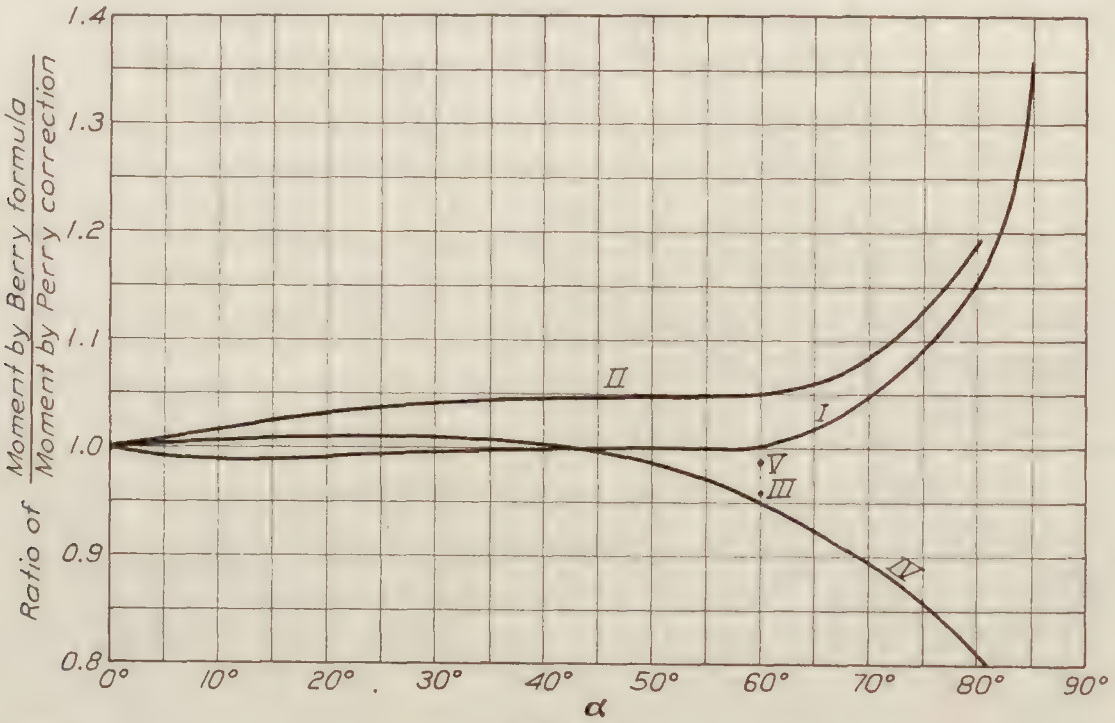


FIG. 15

The application of the Perry formula may of course be extended in this case over the whole range of values of α, again taking n, the coefficient of shift of the points of inflection as 0.2. That has been done in Figure 15, whence it will be seen that in general, as might be expected, the errors arising from the use of an approximation grow larger and larger as the compressive load in the spar comes progressively to the "Euler load." The error is sometimes in one direction, sometimes in the other, and it becomes dangerously large when α exceeds 70° or 75°.

When α exceeds 65° in either bay, or when it has very nearly the same value in the two bays and that value is in excess of 45°, it is advisable that a direct calculation be made for the maximum moment in that bay in which α is largest, or in both if the two values are equal. The process of calculation is much facilitated by the use of charts giving M_B, as may best be shown by an example.

The inner bay in Case VII will be selected for purposes of illustration, and the work carried through with α equal to 60°, the figure already covered in the tabulation. The length of the inner bay in that case was 35 per cent of the total, that of the overhang 20 per cent, and the bending moment at the middle support without column effect is found by the use of the three-moment equation or from the curves in Report No. 214 to be 152. This figure is, of course, based on a unit loading and a total length of 100 inches. Figure 11 indicates a correction factor of 1.13 to be applied to the moment when α is 60° and the length of the outer bay is 45 per cent, giving an approximate moment for M_B of 171. (It happens that the exact value of the moment with column effect has already been determined for this particular case, but the calculation will be carried through on the same basis as if that had not been done.)

A tabulation can now be made as for a representative single-bay spar, but in simplified form.

α	60° (1.047 rad.)
$\sec \alpha$	2.000
$\csc \alpha$	1.155
M_c	0
M_B	171
$\frac{1}{\mu^2}\left(=\frac{l^2}{4\alpha^2}\right)$	279
$\frac{M_B-M_c}{2}$	85.5
(A) $\left(\frac{M_B-M_c}{2}\right)\csc \alpha$	98.6
$\frac{1}{\mu^2}-\frac{M_B+M_c}{2}$	193.5
(B) $\left(\frac{1}{\mu^2}-\frac{M_B+M_c}{2}\right)\sec \alpha$	387
$\tan \mu x\left(=\frac{(A)}{(B)}\right)$	0.255
$\sec \mu x\ (=\sqrt{1+\tan^2 \mu x})$	1.0320
$M_{max.}\left(=(B)\sec \mu x-\frac{1}{\mu^2}\right)$	120

Working to a degree of accuracy of individual figures well within the scope of an ordinary slide-rule, the maximum moment can be calculated with an error of not more than 1 or 2 per cent in only three or four minutes more time than would be needed for the determination of the distance between the points of inflection and the application of Perry's formula or some other approximation of similar nature.

The only assumption involved in the work just done lay in the use of Figure 11 to find M_B. If the correction factor there plotted had been 5 per cent in error, however, so that M_B had been taken as 165 instead of 173, it would have changed the maximum calculated moment in the bay only from 120 to 126, introducing an error of about the same magnitude as that made in M_B itself.

BEST STRUT LOCATION

It was shown in Report No. 214, on the assumption that the Perry formula could be used to take care of the column correction in both bays, that the determining condition for maximum economy of material in an untapered two-bay spar is that the struts shall be so placed that the total resultant stresses at the inner strut, at the outer strut, and at the point of maximum moment in the inner bay are the same. That report also includes calculations of the best strut locations in terms of the relation between span, gap, and depth of spar, indicating that the best length of inner bay ranges from 32 to 40 per cent of the total length of spar, with overhangs correspondingly varying between 21 and 25 per cent. Figure 13 shows that an inner bay length of 32 per cent, combined with a 21 per cent overhang, makes α very slightly larger in the inner bay than in the outer, and any lengthening of the inner bay or shortening of the outer would, of course, increase the superiority of the inner bay α. The proportions recommended in the previous report would therefore make the inner bay the critical one for column effect in all cases in the light of the present analysis.

The Perry formula as used in the earlier work has here been shown to give approximately correct results, but no allowance was there made for the increase of M_B with column effect.

Aside from the absence of such allowance, the conclusions reached in Report No. 214 about strut distribution will still hold, as the inner bay proved the critical one by both treatments, the approximate and the exact. If the change of M_B be taken roughly into account, however, it appears advantageous to increase the length of overhand about 1 per cent while leaving the position of the inner strut unchanged. The curves of strut distribution in Report No. 214 might therefore well be modified by increasing the figure attached to each curve of equal overhand by one unit, making the best arrangement, for a truss of average aspect ratio and gap-chord ratio, an inner bay of 34 per cent, an outer bay of 43, and an overhand of 23. These figures are given for a value of α of 60° in the inner bay, which is about the mean for two-bay biplanes. Any increase in that figure makes a still further increase of overhang advisable.

APPLICATION TO SPARS FIXED AT ENDS

It would be expected that the fixing moment at the inner end of a spar rigidly fixed to center section or fuselage would vary with column effect in the same general way as the moment in the inner bay, for if an increase of compression increases the upward deflection in the inner bay it must increase the curvature of the center line of the spar, and so the bending moments, both in the middle of that bay and at its inner end. It would also be anticipated that the column effect on the magnitudes of mid-bay moments would be less when the end of the spar is fixed than when it is pinned and free to change its slope. The single illustrative calculation made, bearing on a spar of the same proportions as that in Case VII but with a fixed end, has verified that expectation, for when α is 60° in the inner bay and bending moments vary in the manner shown by the tabulation below.

Moments	Inner end pinned			Inner end fixed		
	No column effect	$\alpha=60°$	Ratio	No column effect	$\alpha=60°$	Ratio
Inner strut	153	173	1. 13	134	145	1. 08
Inner end				86	88	1. 02
Inner bay	85	119	1. 40	43	28	. 65

It is impossible to arrive at any very definite conclusion in the absence of more computations, but it seems probable that column effect on the fixing moment at the end of the spar will be of little importance in two-bay spars of usual dimensions, while the correction factor to be applied to that moment in a single-bay spar would always be less than the corresponding factor for the mid-bay moment in the same spar. It is probable, too, that the correction factor for the moment in the inner bay of a two-bay spar fixed at the end will be less than unity except when the value of α in the inner bay exceeds that in the outer by at least 20 per cent, and that in any case, whatever the ratio between those values may be, the use of the Perry formula without any shift of the points of inflection calculated under lateral load alone (that is, with the coefficient n taken equal to zero) will be a safe procedure.

REFERENCES

No. 1. NEWELL, J. S. "The Investigation of Structural Members under Combined Axial and Transverse Loads, Sec. I." Air Service Information Circular No. 493. Dec. 1, 1924.

No. 2. BERRY, ARTHUR. "Calculation of Stresses in Aeroplane Wing Spars." Transactions of the Royal Aeronautical Society No. I.

PIPPARD, A. J. S. and PRITCHARD, J. L. "Aeroplane Structures." Longmans, Green and Co. 1919. Pp. 116–120. (Abbreviated form of proof.) (Modified form dependent on different coordinates given in Reference 1.) (A similar method was developed in Germany during the war of 1914–1918.)

No. 3. WARNER, EDWARD P. "Wing Spar Stresses and Stress Charts." National Advisory Committee for Aeronautics Technical Report No. 214. 1925.

No. 4. MORLEY, A. "Strength of Materials."

No. 5. WARNER, EDWARD P. "Notes on Wing Spar Design." Aviation, May 20, 1922.

REPORT No. 252

THE DIRECT MEASUREMENT OF ENGINE POWER ON AN AIRPLANE IN FLIGHT WITH A HUB TYPE DYNAMOMETER

By W. D. GOVE and M. W. GREEN
Langley Memorial Aeronautical Laboratory

REPORT No. 252

THE DIRECT MEASUREMENT OF ENGINE POWER ON AN AIRPLANE IN FLIGHT WITH A HUB TYPE DYNAMOMETER

By W. D. Gove and M. W. Green

SUMMARY

This report describes tests made at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics to obtain direct measurements of engine power in flight. Tests were made with a Bendemann hub dynamometer installed on a modified DH-4 airplane, Liberty 12 engine, to determine the suitability of this apparatus.

This dynamometer unit, which was designed specially for use with a Liberty 12 engine, is a special propeller hub in which is incorporated a system of pistons and cylinders interposed between the propeller and the engine crankshaft. The torque and thrust forces are balanced by fluid pressures, which are recorded by instruments in the cockpit.

These tests have shown the suitability of this type of hub dynamometer for measurement of power in flight and for the determination of the torque and power coefficients of the propeller.

INTRODUCTION

A more complete knowledge of the power developed by airplane engines under the varying atmospheric conditions encountered during flight is of practical value in the development of aircraft. Indirect methods have been used in an effort to determine the variation of engine power with altitude. A common method is to use ground-level engine performance as a basis and to compute power by applying corrections for changes in temperature and pressure. Because of differences in volumetric efficiency, air fuel ratio, and mixture distribution the effect of altitude on the performance of aviation engines is somewhat variable. The correction of ground-level power of any one engine according to a general law is therefore only approximate. Power in flight can also be computed from propeller characteristics as determined from model propeller tests. This method is subject to errors resulting from indeterminate factors, such as the effect of fuselage interference and scale effect. A full-size propeller calibrated in place would furnish the data desired. It is obvious that more reliable information on any one engine could be expected from measurement of power under actual flight conditions.

Indicated horsepower has been measured by the Royal Aircraft Establishment at altitude by means of the R. A. E. electrical indicator. (Reference 1.) Conversion of I. HP. to B. HP. depends on a knowledge of the variation of the mechanical efficiency with density. An apparatus which measures directly torque in the crankshaft simplifies the determination of B. HP.

A hydraulic torque meter which was also arranged to measure thrust was developed by the D. V. L. (Deutsche Versuchsanstalt für Luftfahrt) laboratories in Germany before the close of the war. The apparatus was actually used in flight. (References 2 and 3.) Such a unit suitable for measuring the power of a Liberty engine was purchased by the United States Navy in 1924 and later used in these tests.

The suitability of this apparatus for flight test work was investigated while determining the variation in torque coefficient of the propeller with V/nD. Data were also obtained as to the variation in B. HP. of the engine with altitude. Since the apparatus measures tension in the crankshaft rather than effective thrust, the records of thrust were not considered.

DESCRIPTION OF APPARATUS

The Bendemann hub dynamometer consists of a special propeller hub in which is incorporated a set of small pistons and cylinders interposed between the engine shaft and the propeller in such a manner that the torque and thrust forces are balanced by fluid pressures in a closed hydraulic system. The fluid pressures so obtained, which are a measure of torque and thrust, are transmitted to suitable recording instruments in the cockpit. Since an apparatus of this type has not been used before in this country, a detailed description is given.

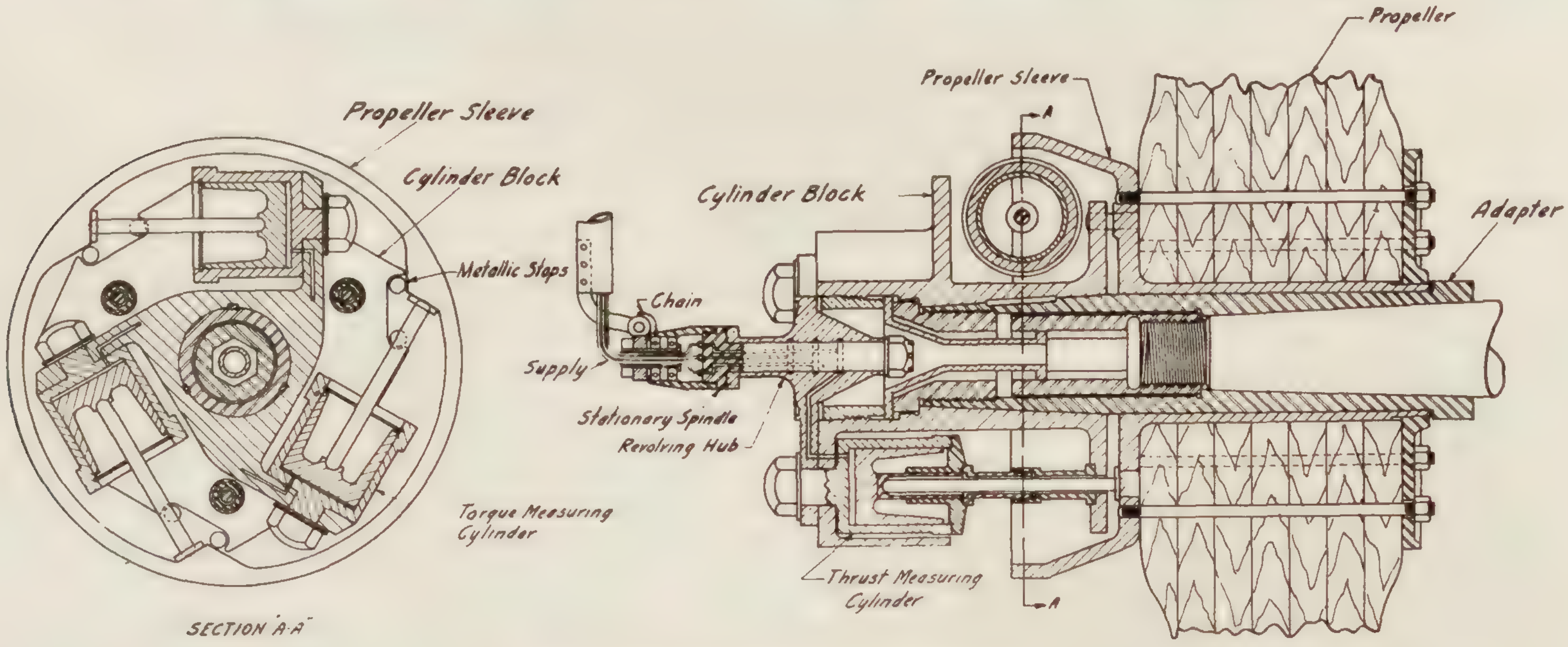


FIG. 1.—Sectional view of dynamometer hub

The dynamometer hub replaces the conventional propeller hub and allows the propeller to be mounted in its original position relative to the engine. The dynamometer mechanism is placed just ahead of the propeller, as shown in sectional views, Figure 1. It consists essentially of: (1) A steel sleeve adapter keyed to the engine crankshaft; (2) a cast-steel propeller sleeve which is a loose fit on the adapter; (3) a cast-steel cylinder block which is keyed to the adapter and contains the torque and thrust cylinders and drilled passages for transmitting working fluid to the cylinders; (4) a bronze spider and revolving hub containing drilled passages which register with the passages in the cylinder block to which it is bolted; and (5) a stationary spindle which contains drilled passages connecting with annular grooves in the revolving hub at one end and with tubes connecting the dynamometer hub with the recording instruments at the other end. The weight of the hub unit is 128 pounds.

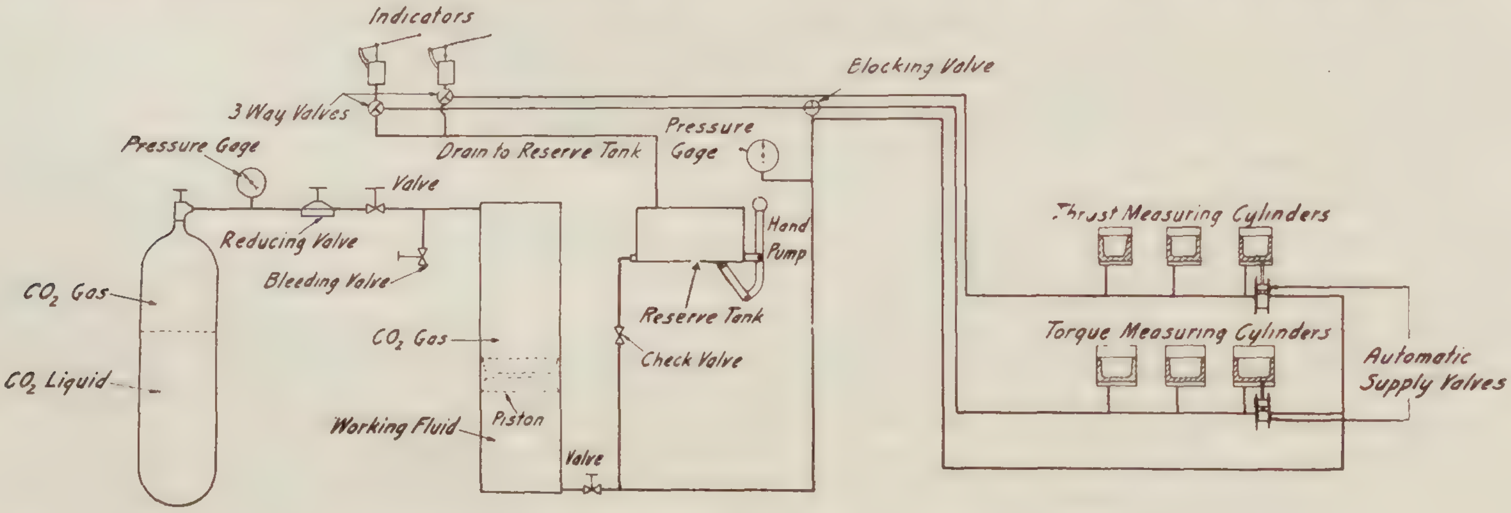


FIG. 2.—Diagrammatic sketch of Bendemann hub dynamometer

The propeller sleeve is a running fit on the crankshaft adapter and is free to oscillate a few degrees and to slide axially a distance of one-eighth inch. Its rotational motion is limited by metal stops on the cylinder block and its axial travel is restricted by the rear shoulder on the adapter and the cylinder block. The stops mentioned serve to drive the propeller in case of loss of liquid in the hydraulic system. Steel piston rods having hemispherical ends which rest in steel sockets at either end are interposed between the pistons in the cylinder block and the propeller sleeve and are of such length as to hold the propeller sleeve free of the stop lugs when the pistons are in working position.

The working fluid is introduced under all the pistons, and the fluid pressures generated in the cylinders by the torque and thrust forces are recorded.

Figure 2 gives a diagrammatic sketch of the complete dynamometer apparatus and shows the operation of the hydraulic system. A high-pressure supply of fluid is used to compensate for any leakage in the systems. Since each set of cylinders has connecting passages, admission of supply fluid is controlled by only one automatic valve on each set of three measuring pistons. Figures 3 and 3a show a torque-measuring piston and cylinder with the automatic supply valve.

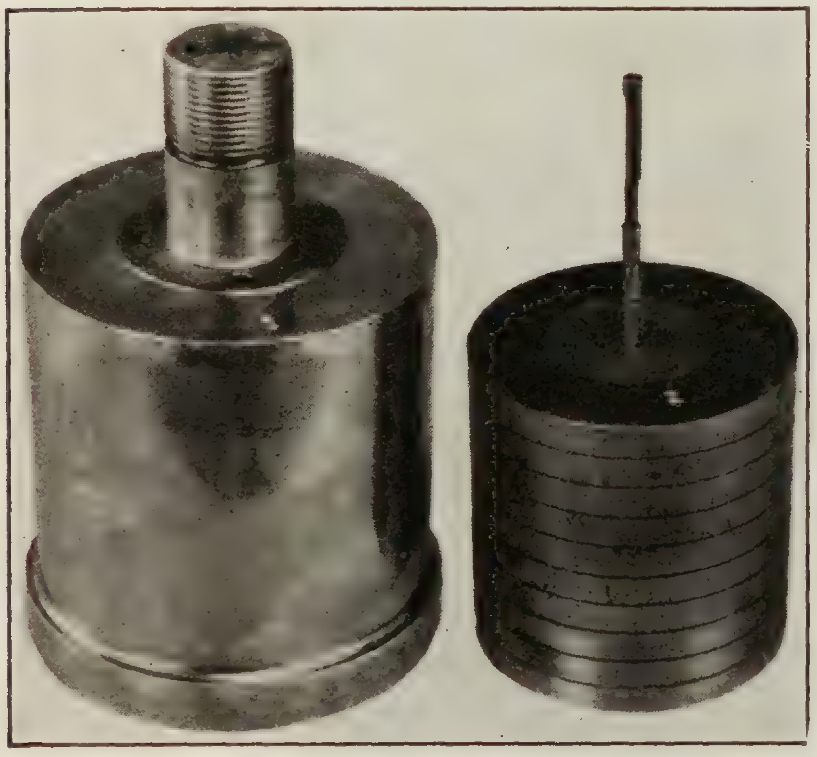


FIG. 3

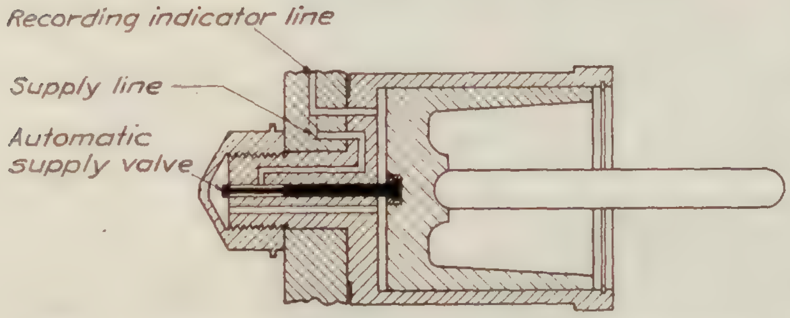


FIG. 3a.—Views and section of torque-measuring clyinder showing automatic supply valve

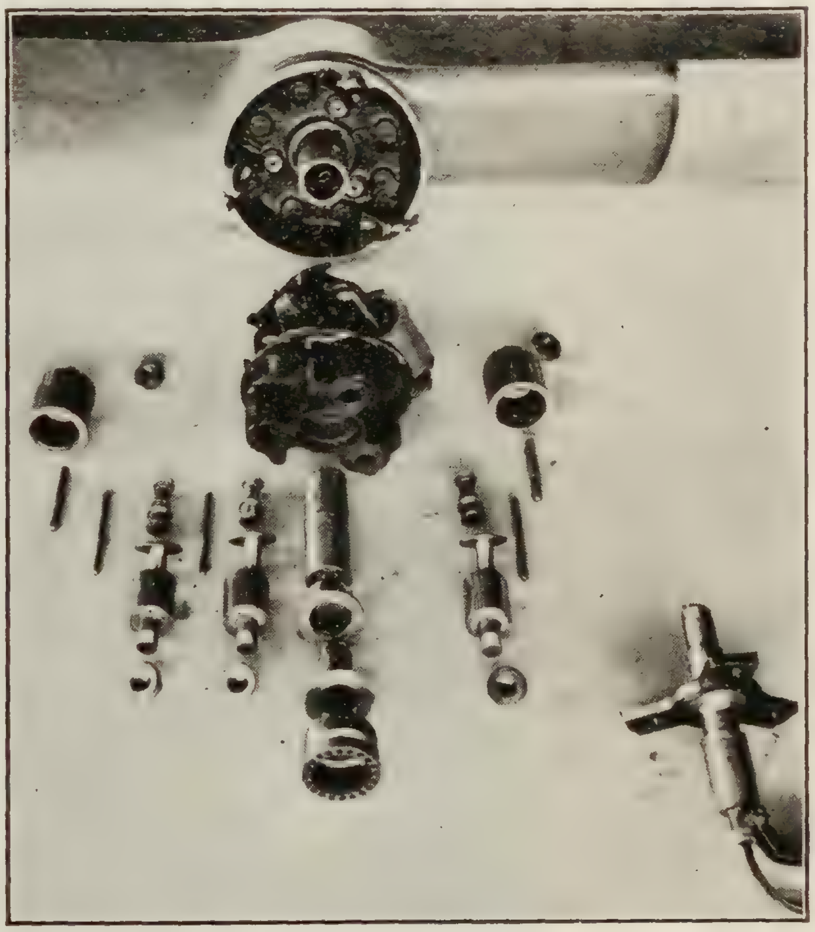


FIG. 4.—General view of hub parts

This valve is only opened when leakage causes the piston to approach the cylinder head and closes as soon as the fluid is replaced. This regulating valve is the outstanding feature of the dynamometer, and the regulation is adjusted to such a nicety that the motion of the piston is barely perceptible, and the indicator records do not show when the new fluid is admitted. Figure 4 shows the hub unit disassembled.

The rotating hub and the stationary tubing of the thrust, torque, and supply systems are connected as shown in Figure 1. The lines are connected to a stationary spindle whose radial holes register with annular grooves in the revolving hub. It is necessary to carry the tubing from the stationary spindle over the propeller to the controlling and recording apparatus in the cockpit. The torque and thrust lines lead to their respective recording instruments, each of which consists of a spring-loaded piston actuating an indicator arm carrying a brass stylus which traces a line on metallic-faced paper. A drum, revolved at constant speed by a clockwork, carries this paper. A third stylus traces a reference line.

The supply line is served by a tank containing the working fluid. (See fig. 2.) Pressure in the supply tank is maintained by gas acting on a piston, the latter serving to separate the gas from the working fluid and to prevent absorption of the gas. A steel bottle partially filled with liquid carbon dioxide supplies the gas pressure, which is controlled by a regulating valve.

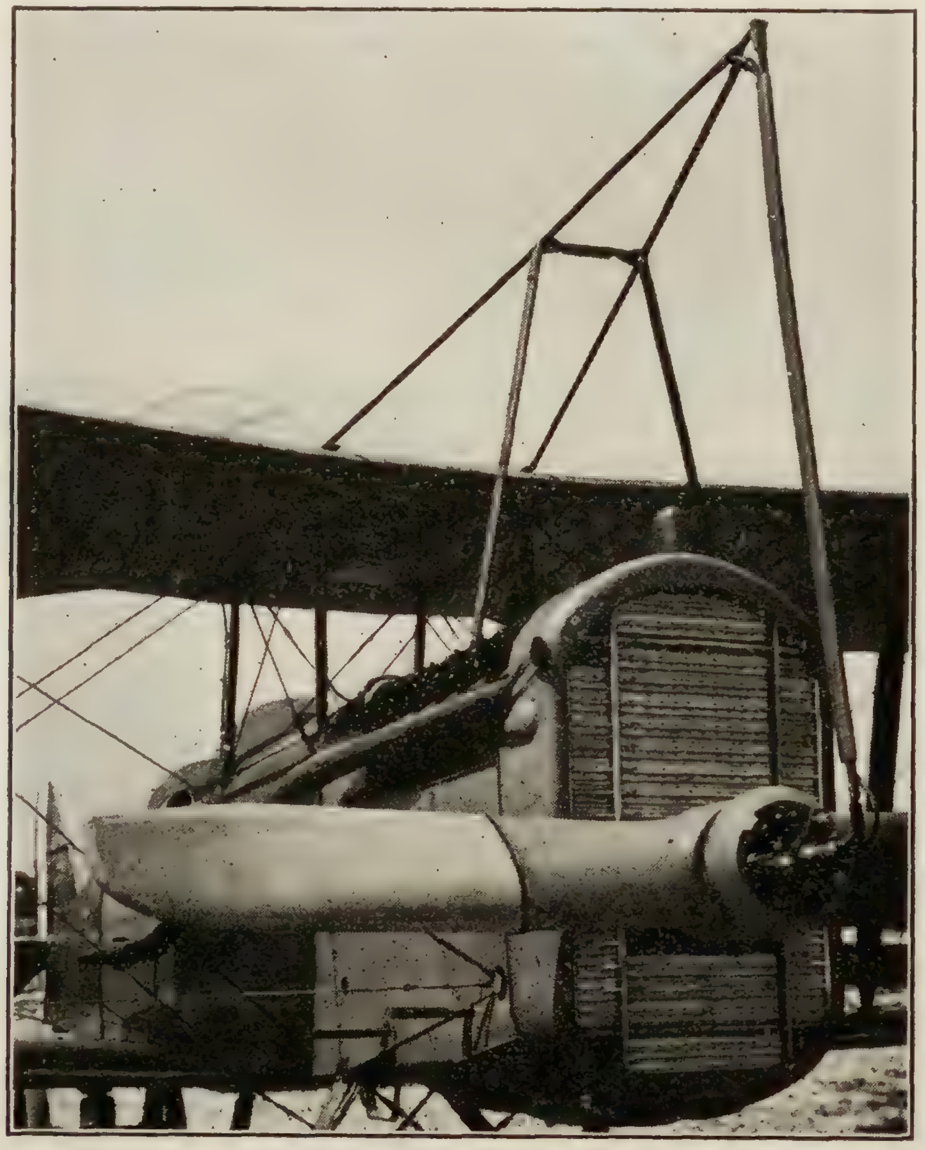


FIG. 5.—Installation in modified DH-4 airplane

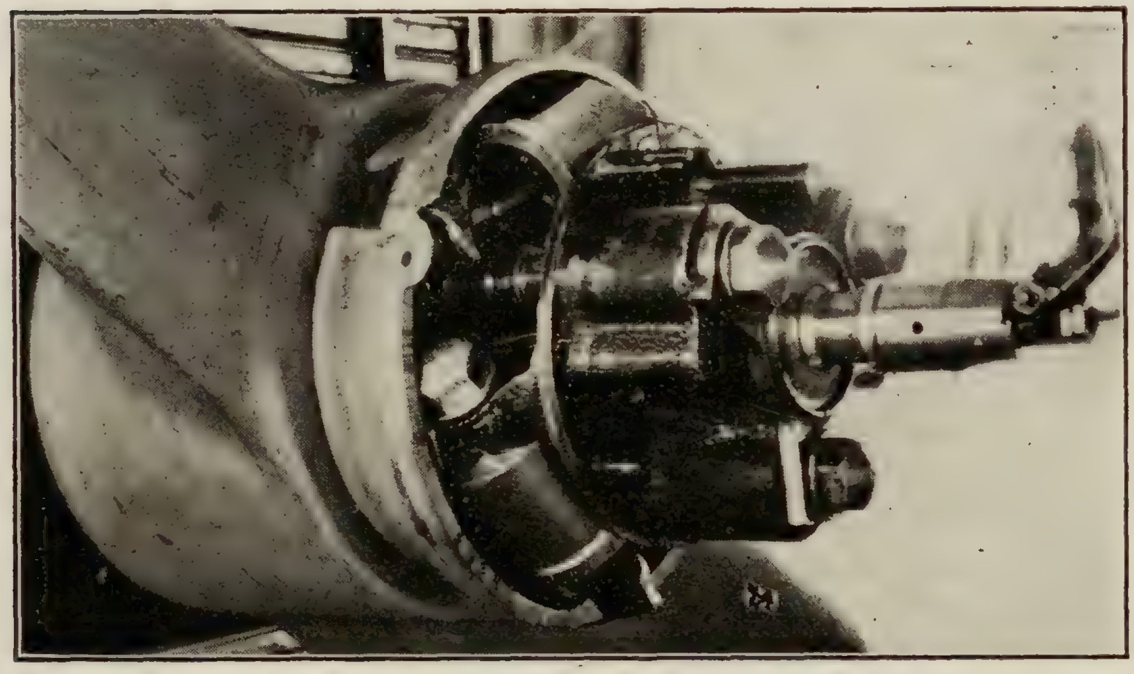


FIG. 6

The supply tank containing the working fluid can be replenished from a reserve tank by actuating a hand pump, fluid being pumped in under the piston. Pressure in the supply system is maintained at about 425 pounds per square inch, and the pressures in the torque and thrust systems never exceed 275 pounds per square inch.

Provision is made whereby the high supply pressure can be admitted to the torque-measuring cylinders, forcing the pistons out and locking the propeller sleeve against the metal stops. The propeller is locked in this way during glides or when the engine operates irregularly.

A typical installation is shown in a modified DH-4 airplane, Liberty 12 engine (figs. 5 and 6). It may be noted that there is considerable overhung weight at the propeller hub and that the tubing must be led around the propeller. Figure 7 shows the controlling and recording apparatus in the cockpit. The apparatus is quite bulky and requires considerable space.

In addition to the hub dynamometer, the following N. A. C. A. instruments were used during flight tests: Recording altimeter, recording air-speed meter, and automatic observer. (Reference 4.)

For measuring air speed a swivel-type Pitot static head mounted on the outer strut at a point about one-third the gap from the top wing was used. The automatic observer recorded the air temperature from the indicator of an electric resistance thermometer. The engine speed was recorded by the automatic observer from a service-type tachometer. A distance-type thermometer was used to measure carburetor-air temperature, as it generally differs from the free-air temperature.

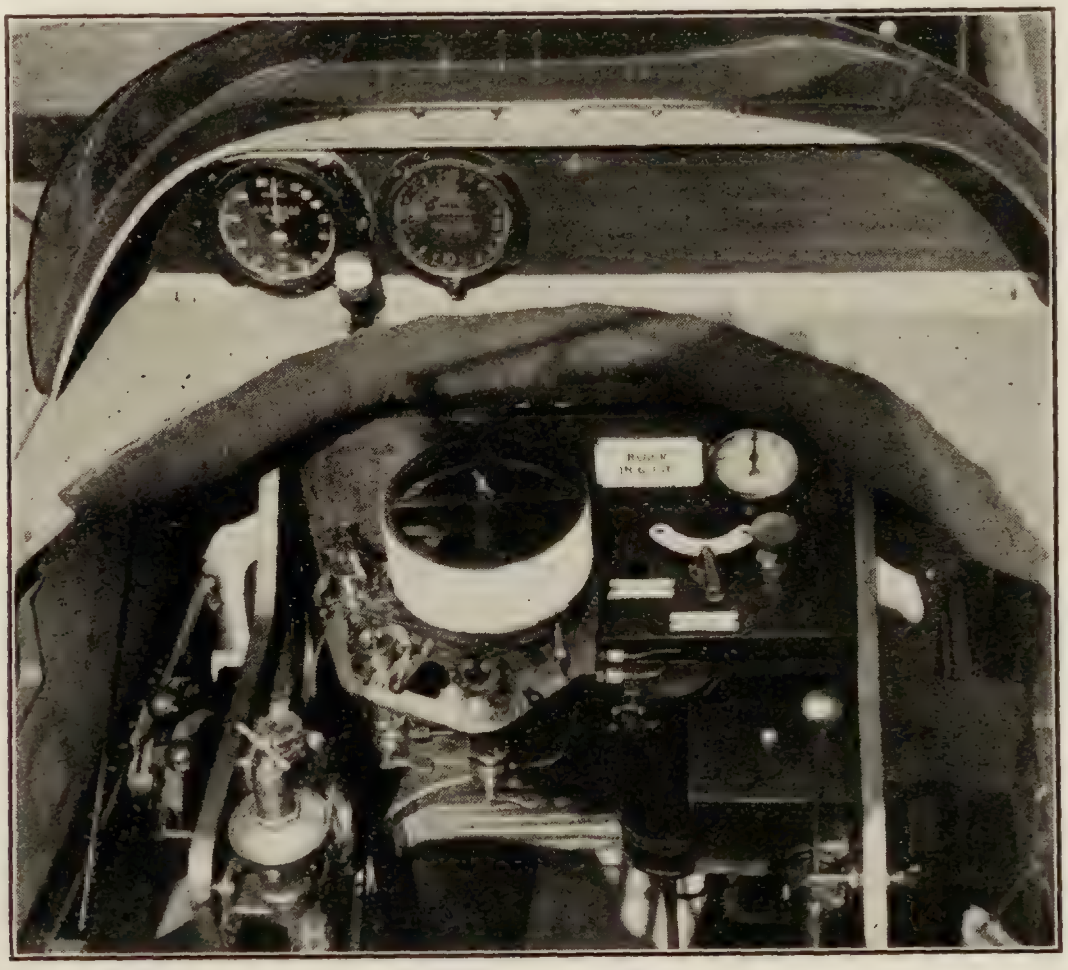


FIG. 7.—View of recording apparatus in cockpit

METHODS

PRELIMINARY TESTS

For preliminary test the dynamometer with a propeller was mounted on a portable test stand. Tests were made to determine the general operation and the nature of the further investigation required. It was found desirable to calibrate the apparatus in the laboratory against measured torque.

A fan brake was substituted for the propeller and the hub set up so that it would be driven by an electric dynamometer. The apparatus was then calibrated against the torque measurements of the electric dynamometer. In addition, static load calibrations of torque were made by holding the shaft rigid and applying known values of torque to the propeller sleeve.

A 2 to 1 mixture of glycerin and alcohol was selected as the most suitable working fluid, because it was sufficiently viscous to prevent excessive leakage around the pistons and its viscosity was least influenced by temperatures. A calibration of indicator deflection against measured torque was made with the 2 to 1 mixture of glycerin and ethyl alcohol. This curve is shown in Figure 8 with a computed curve which agrees closely with it. The computed curve was based on the dimensions of the dynamometer parts and unit pressures.

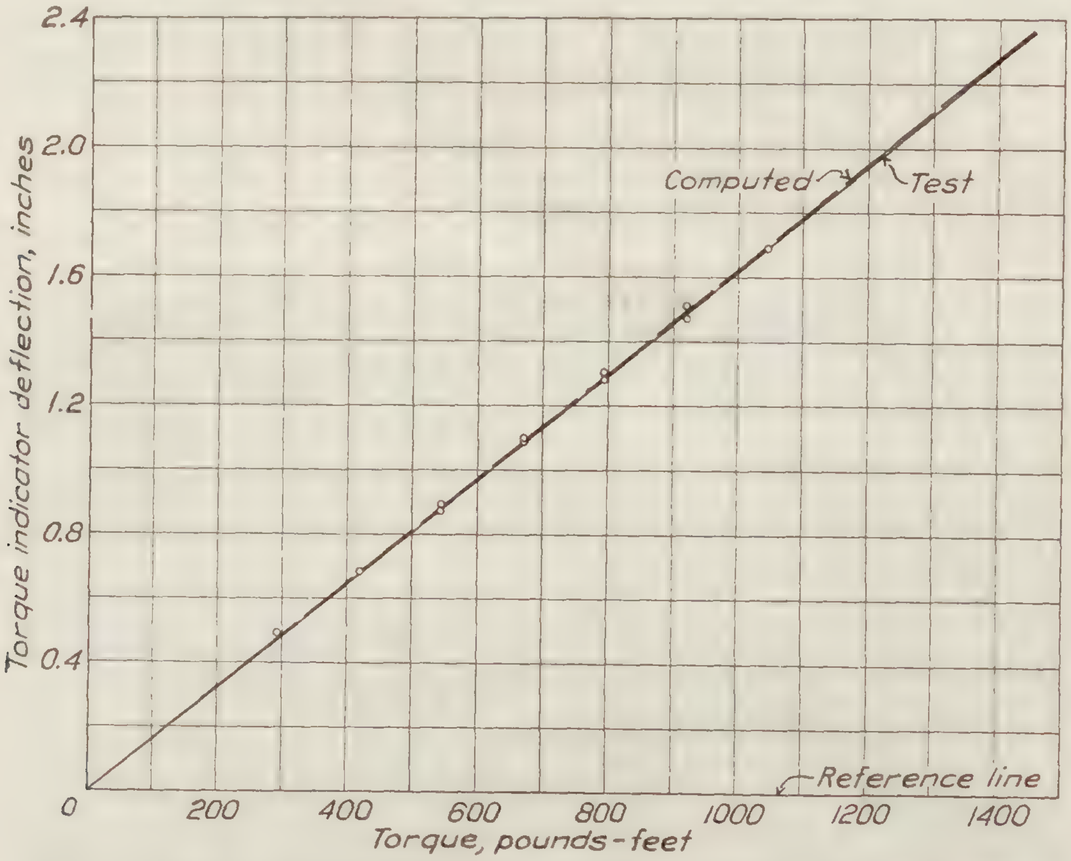


FIG. 8.—Calibration with 67 per cent glycerin and 33 per cent alcohol. Indicator deflection versus torque

FLIGHT TESTS

The flight tests were made for the dual purpose of obtaining data for the variation of torque coefficient of the propeller with V/nD and for the variation of full-throttle engine power with altitude. A series of full-throttle short climbs past a given altitude were made at various air speeds to cover a range of V/nD. The series was repeated at four altitude stations, the highest of which was 12,000 feet.

All records except those of the hub dynamometer were synchronized by timing lines. The dynamometer recording drum was always started at the same time as the other instruments, and since it turns at a known constant speed, it was easily synchronized with the other instruments.

DISCUSSION OF RESULTS

FLIGHT TESTS

Torque coefficients computed from data taken at the four altitude stations are plotted against V/nD in Figure 9. The torque coefficient determined was that given by the equation

$$C_q=\frac{Q}{\rho V^2 D^3},$$

where C_q is torque coefficient, Q is torque in pounds-feet, ρ is mass density of the air in pounds-feet-seconds, V is velocity of advance of the airplane in feet per second, D is diameter of the propeller in feet.

The points shown in the curve, Figure 9, represent data taken at different air densities. The fact that all points lie near an average curve demonstrates the practicability of calibrating a propeller at a convenient altitude with the hub dynamometer for the complete working range of V/nD. A propeller calibrated by such a method would be particularly useful for measuring engine power at any altitude on supercharged engines, or on other tests where it is not practicable to use the hub dynamometer.

As the determination of the torque coefficient of the propeller is independent of engine operation, the variation of test points from the average curve of torque coefficient against V/nD was considered a reasonable basis for determining the precision of this method of measuring power. The maximum variation of the test points from the curve, Figure 9, is 4½ per cent. This value includes errors in the measurement of R. P. M., air speed and density, as well as in the measurement of torque.

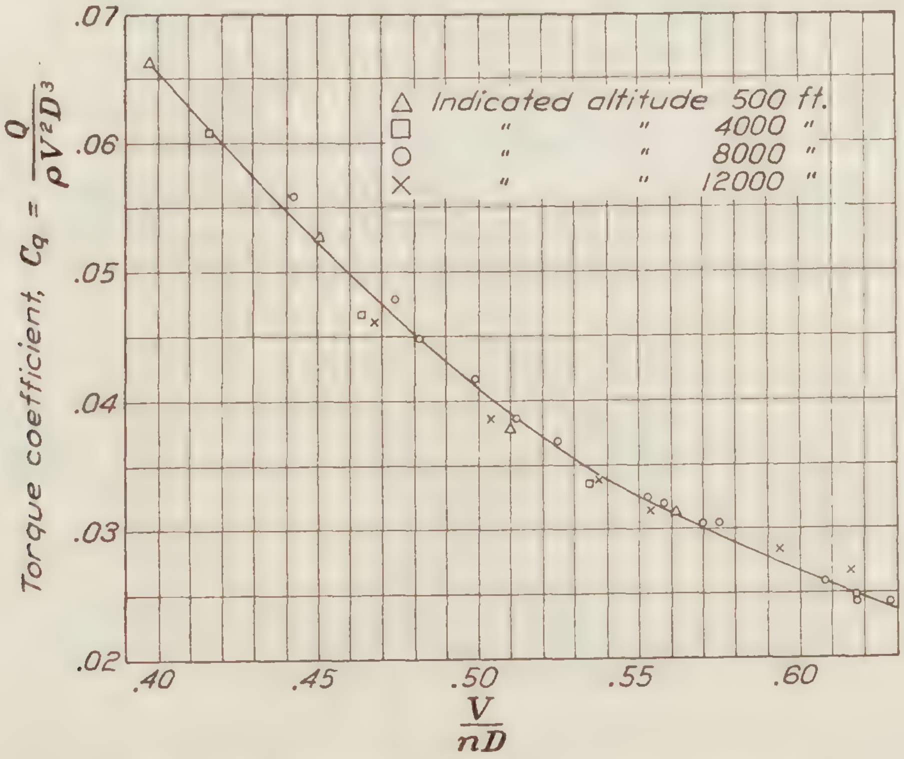


FIG. 9.—Torque coefficient versus V/nD. U. S. 12 propeller

Figure 10 shows a curve of measured brake power against carburetor air density. All points represent full-throttle measured power at various engine speeds corrected by proportion to the mean speed of 1,650 R. P. M. It was considered best to plot power against carburetor air density, since the carburetor air temperature was always found to be higher than that of the surrounding air. Engine operation was not up to standard during the tests, due, it was found later, to the fact that there had been a leak in the ignition system.

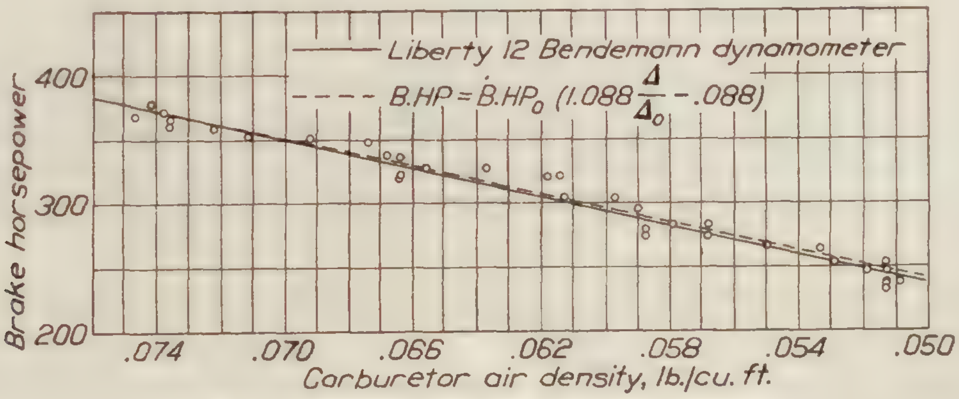


FIG. 10.—Brake horsepower versus carburetor air density

Although not conclusive, the results obtained on this one engine are indicative of the variation in power with density and represent data taken under actual operating conditions. The measured curve of power against density shown in Figure 10 agrees reasonably well with a curve computed from the relation

$$\text{B. HP.} = \text{B. HP.}_0 \left(1.088 \frac{\Delta}{\Delta_0} - .088\right),$$

where $B. HP_0$ and Δ_0 are respectively ground-level brake horsepower and density. This formula may be taken as representative of methods of computing power at altitude arrived at from theoretical considerations (Reference 5).

SUITABILITY OF BENDEMANN HUB DYNAMOMETER

Tests in the laboratory, using fluids of varying viscosity, show that the viscesity has little effect on the calibration of the hub dynamometer. Figure 11 shows calibrations made with a variety of working fluids, varying in viscosity from that of kerosene to that of castor oil. The total variation in calibration at 1,400 pounds-feet torque is 2.7 per cent. Any change in viscosity of the working fluid resulting from temperature changes encountered at moderate altitudes is well within the range of viscosities covered in these tests. The use of low-viscosity liquids, while not materially affecting the calibration, result in excessive leakage. The use of the apparatus is limited to moderate altitudes (15,000 to 20,000 feet), because any fluid of proper viscosity at ground level tends to solidify at the lower temperatures.

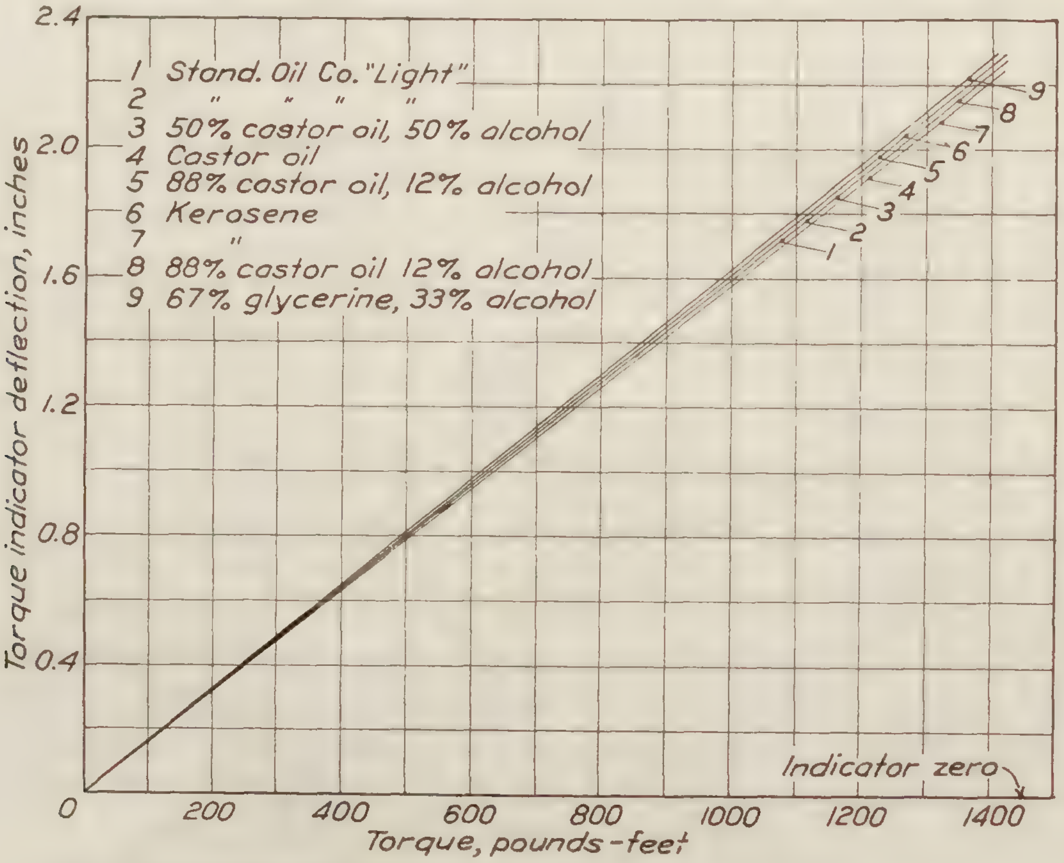


FIG. 11.—Calibrations with various working fluids. Indicator deflections versus torque

The general operation of the apparatus in flight was fairly satisfactory, with the exception that toward the end of the tests the dynamometer hub unit developed considerable vibration, which was attributed in part to the fact that the white-metal lining of the propeller sleeve on the adapter pounded loose and to the fact that the unit was found to be somewhat out of balance after the tests.

A very desirable improvement in the apparatus would be the elimination of the necessity for carrying the tubing around the propeller. This would eliminate any interference of the bracing around the propeller and its possible influence on propeller characteristics. A new design should also make the apparatus fully automatic.

The results of this investigation indicate that the Bendemann type hub dynamometer, with some limitations, is suitable for the measurement of engine power in flight for a moderate range of altitude.

CONCLUSION

The Bendemann type of hub dynamometer can be used successfully to determine the variation of the torque coefficient of the propeller with V/nD. As the torque coefficient for any one value of V/nD is constant regardless of altitude, a propeller calibrated by the hub dynamometer is then made available for measuring power on tests where it is not practical to carry the dynamometer unit. The feature is especially applicable to the measurement of power on supercharged engines.

Engine operation at full throttle was not completely satisfactory during this investigation, but the incidental information concerning the variation of engine power with density conforms closely to that obtained from the equation

$$\text{B. HP.} = \text{B. HP.}_0 \left(1.088 \frac{\Delta}{\Delta_0} - .088\right). \quad \text{(Reference 5.)}$$

It is recommended that further flight research be undertaken to obtain additional and reliable information regarding the variation in brake power with density.

Experience with the present design has shown that it could be improved by reducing the weight of the hub unit, by making the apparatus fully automatic in operation, and by eliminating the necessity for carrying the tubing around the propeller.

REFERENCES

1. Staff, Royal Aircraft Establishment. Flight Tests with Royal Aircraft Establishment Electrical Indicator. Aeronautical Research Committee R. & M. No. 880, 1924.
2. Enoch, O. The Dynamometer Hub for Testing Engines during Flight. N. A. C. A. Technical Note No. 59, 1921.
3. Stieber, W. Stieber Dynamometer Hub for Aircraft Propellers. N. A. C. A. Technical Memorandum No. 288, 1924.
4. Norton, F. H. N. A. C. A. Recording Air-speed Meter. N. A. C. A. Technical Note No. 64, 1921.
5. Engineering Division, Air Service. Handbook of Instructions for Airplane Designers, 1925, 4th ed., McCook Field, p. 114.

REPORT No. 253

FLOW AND DRAG FORMULAS FOR SIMPLE QUADRICS

By A. F. ZAHM
Aerodynamical Laboratory, Bureau of Construction and Repair, U. S. Navy

REPORT No. 253

FLOW AND DRAG FORMULAS FOR SIMPLE QUADRICS

By A. F. Zahm

PREFACE

In this text are given the pressure distribution and resistance found by theory and experiment for simple quadrics fixed in an infinite uniform stream of practically incompressible fluid. The experimental values pertain to air and some liquids, especially water; the theoretical refer sometimes to perfect, again to viscid fluids. For the cases treated the concordance of theory and measurement is so close as to make a résumé of results desirable. Incidentally formulas for the velocity at all points of the flow field are given, some being new forms for ready use derived in a previous paper and given in Tables I, III. A summary is given on page 536.

The computations and diagrams were made by Mr. F. A. Louden. The present text is a slightly revised and extended form of Report No. 312, prepared by the writer for the Bureau of Aeronautics in June, 1926, and by it released for publication by the National Advisory Committee for Aeronautics. A list of symbols follows the text.

PRESSURE AND PRESSURE DRAG

We assume the fluid, of constant density and unaffected by weight or viscosity, to have in all the distant field a uniform velocity q_0 parallel to x; in the near field the resultant velocity q. If now the distant pressure is everywhere p_0, and the pressure at any point in the disturbed flow is p_0+p, the superstream pressure p is given by Bernouilli's formula,

$$p/p_n = 1 - q^2/q_0^2, \tag{1}$$

where $p_n = \rho q_0^2/2$, called the "stop" or "stagnation" or "nose" pressure.

At any surface element the superpressure exerts the drag $\int p \, dy \, dz$, whose integral over any zone[1] of the surface is the zonal pressure drag,

$$D = \int p \, dy \, dz. \tag{2}$$

Values of p, D are here derived for various solid forms and compared with those found by experiment.

PRESSURE MEASUREMENTS

The measured pressures here plotted were obtained from some tests by Mr. R. H. Smith and myself in the United States Navy 8-foot wind tunnel at 40 miles an hour. Very accurate models of brass, or faced with brass, had numerous fine perforations, one at the nose, others further aft, which could be joined in pairs to a manometer through fine tubing. Thus the pressure difference between the nose and each after hole could be observed for any wind speed. Then a fine tube with closed tip and static side holes was held along stream at many points abreast of the model, to show the difference of pressure there and at the nose. Next the tube was thrust right through the model, to find the static pressure before and behind it. The method is too well known to require further description.

THE SPHERE

Assume as the fixed body a sphere, of radius a, in a uniform stream of inviscid liquid, as shown in Table I. Then by that table the flow speeds at points on the axis x, y and on the surface are

$$q_x = (1 - a^3/x^3) q_0, \qquad q_y = (1 + a^3/2y^3) q_0, \qquad q_t = 1.5 q_0 \sin\theta, \tag{3}$$

where θ is the polar angle. Figure 1 shows plots of these equations.

---

[1] A zone is a part of the surface bounded by two planes normal to q_0. Usually one plane is assumed tangent to the surface at its upstream end.

To graph p/p_n in Figure 1, we subtract from the line $y=1$, first q_x^2/q_0^2 to show the pressure along x; then q_t^2/q_0^2 to portray the surface pressure. A similar procedure gives the superpressure in the equatorial plane.

The little circles show the actual superpressures found with a 2-inch brass sphere in a tunnel wind at 40 miles an hour. These agree well with the computed pressures except where or near where the flow is naturally turbulent.

By (3) and (1), on the sphere's surface $p/p_n = 1-2.25 \sin^2\theta$; hence the zonal pressure drag $\int p.2\pi y dy$ is

$$D=\pi a^2 \sin^2\theta\left(1-\frac{9}{8}\sin^2\theta\right)p_n, \tag{4}$$

for a nose cap whose polar angle is θ. With increase of θ, as in Figure 2, D/p_n increases to a maximum .698 a^2 for $\theta=41°-50'$ and $p=0$; then decreases to zero for $\theta=70°-37'$; then to its minimum $-.3927\ a^2$ for $\theta=\pi/2$; then continues aft of the equator symmetrical with its fore part. Thus the drag is decidedly upstream on the front half and equally downstream on the rear half, having zero resultant. The little crosses, giving D/p_n for the measured pressures, show that the total pressure drag in air is downstream, and fairly large for a body so blunt as the sphere.

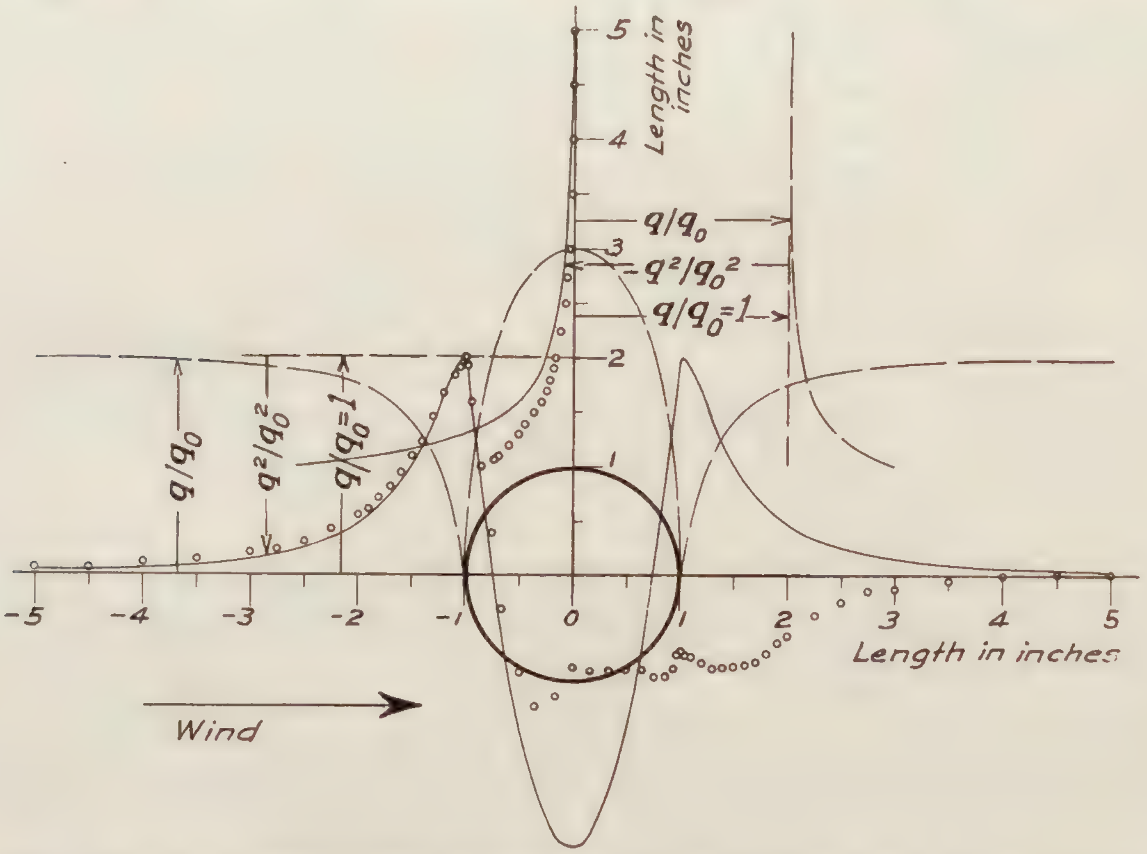


FIG. 1.—Velocity and pressure along axes and over surface of sphere; graphs indicate theoretical values: circles indicate pressures measured at 40 miles per hour in 8-foot wind tunnel, United States Navy

Figure 3 depicts the whole-drag coefficient [2] $C_D = 2D/\pi\ \rho\ a^2 q_0^2$, of a sphere, for the manifold experimental conditions specified in the diagram, plotted against Reynolds Number $R=2\ q_0 a/\nu$, ν being the kinematic viscosity. For $0.2<R<200000$, the data lie close to the line.

$$C_D=28R^{-.85}+.48, \tag{5}$$

an empirical formula devised by the writer as an approximation.

For $.5<R<2$ (5) fairly merges with Oseen's formula

$$C_D=24R^{-1}+4.5, \tag{6}$$

and for $R<.2$ Stokes' equation $C_D=24/R$ is exactly verified. Both these formulas are theoretical. Stokes treated only viscous resistance at small scale; Oseen added to Stokes' drag coefficient, $24/R$, the term 4.5 due to inertia.

---

[2] From the drag $D=C_D p_n S$, where S is the model's frontal area, one derives the drag coefficient $C_D=D/p_n S$.

Over an important R range Figure 3 shows $C_D = .5$, giving as the sphere's whole drag

$$D = .5\ p_n\ S, \tag{7}$$

where $S = \pi\ a^2$ is the frontal area. That is, the sphere's drag equals half its nose pressure times its frontal area. For $R < .2$ Stokes' value, $D = 6\pi\ \mu\ a\ q_0$, has been exactly verified experimentally, as is well known.

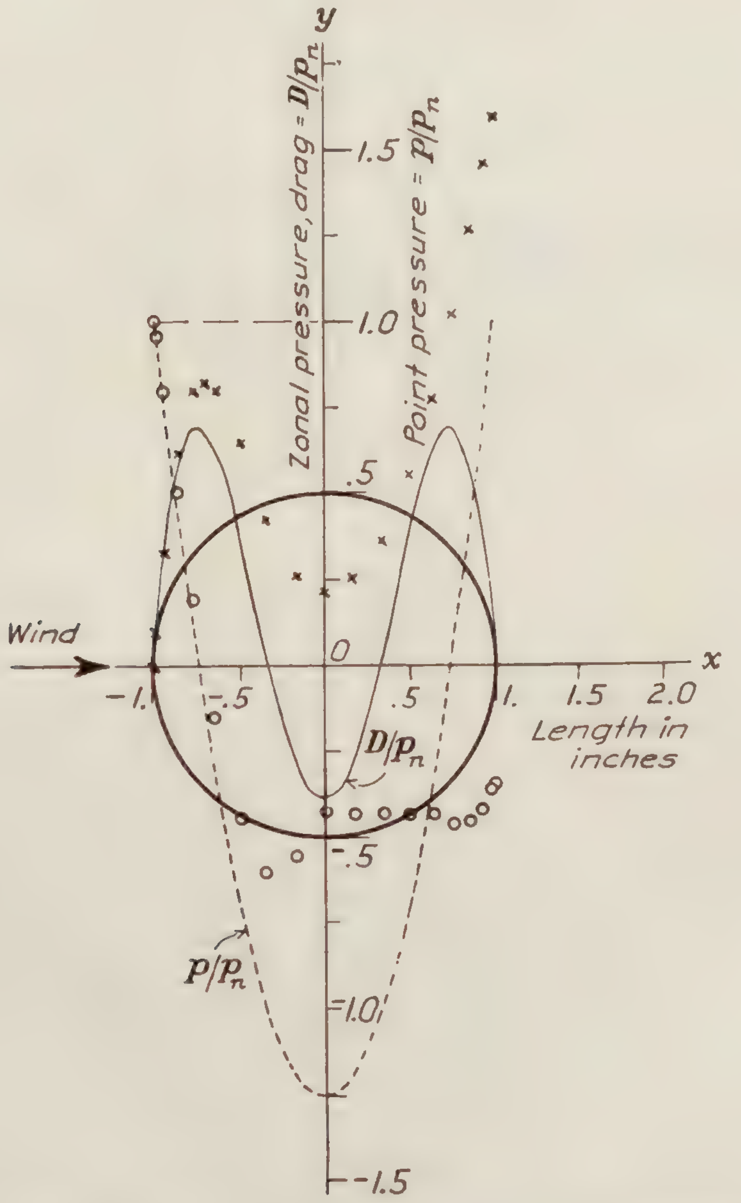


FIG. 2.—Pressure and pressure-drag on sphere. Graphs indicate theoretical values; circles indicate pressure p/p_n measured at 40 miles per hour; crosses indicate pressure-drag D/p_n, computed from measured pressure

THE ROUND CYLINDER

Next assume an endless circular cylinder, of radius a, fixed transverse to the stream, as indicated in Table I. By that table the flow speed at points on the axes x, y and on the surface is

$$q_x = (1 - a^2/x^2)\ q_0,\ q_y = (1 + a^2/y^2)\ q_0, \qquad q_t = 2\ q_0 \sin\theta, \tag{8}$$

where θ is the polar angle. Plots of (8) are shown in Figure 4.

Graphs of p/p_n, made as explained for the sphere, are also given there, together with experimental values, marked by small circles, for an endless 2-inch cylinder in a tunnel wind at 40 miles an hour. The agreement is good for points well within the smooth-flow region.

On the surface $p/p_n = 1 - 4\ \sin^2\theta$. The integral $2\int_0^y pdy$ gives, per unit length of cylinder, the zonal pressure-drag formula,

$$D/p_n = 2\ a \sin\theta - \frac{8}{3} a \sin^3\theta. \tag{9}$$

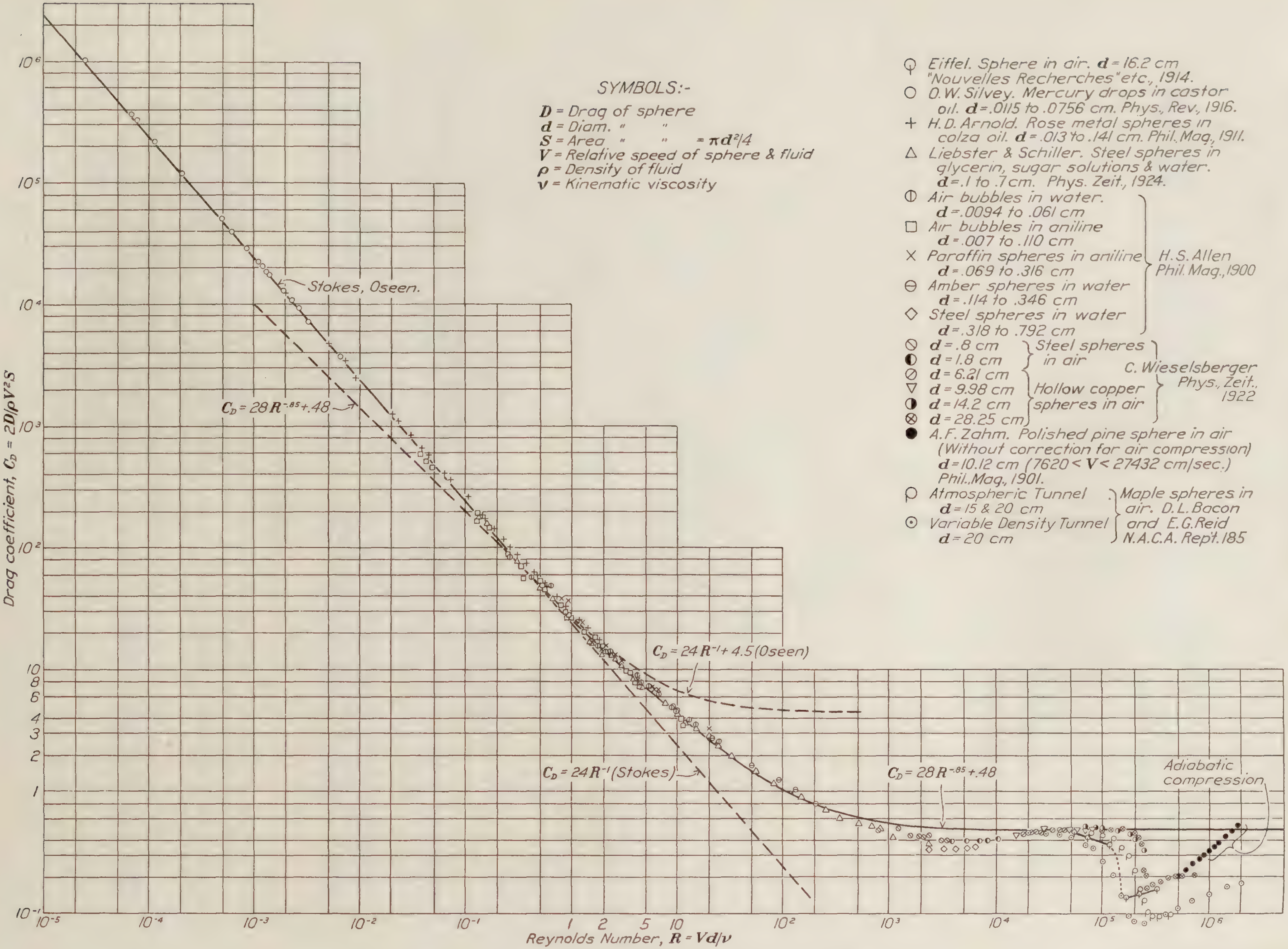


FIG. 3.—Drag coefficient for a sphere in steady translation through a viscous fluid

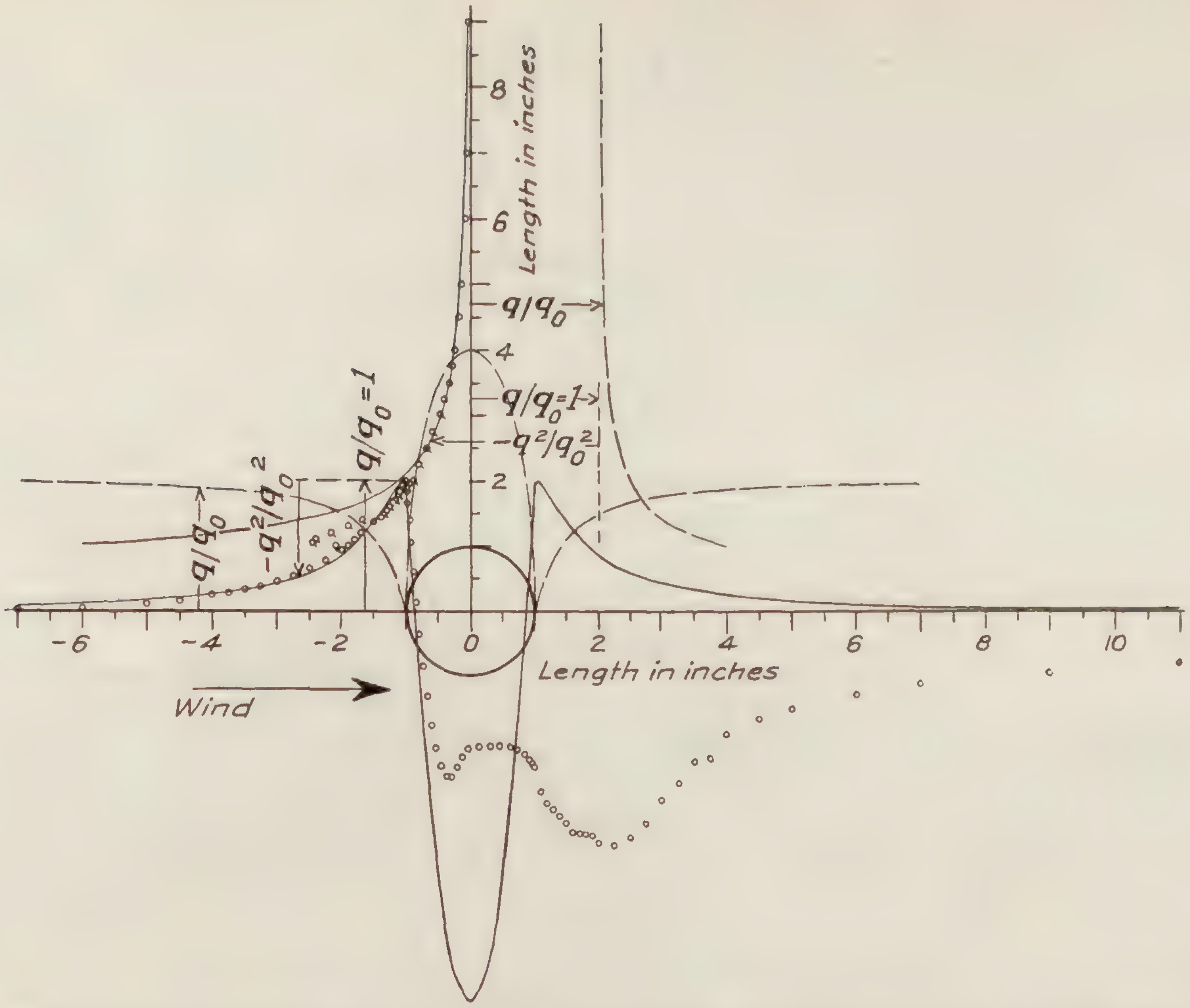


FIG. 4.—Velocity and pressures along axes and over surface of endless cylinder; graphs indicate theoretical values; circles indicate pressures measured at 40 miles per hour in 8-foot wind tunnel, United States Navy

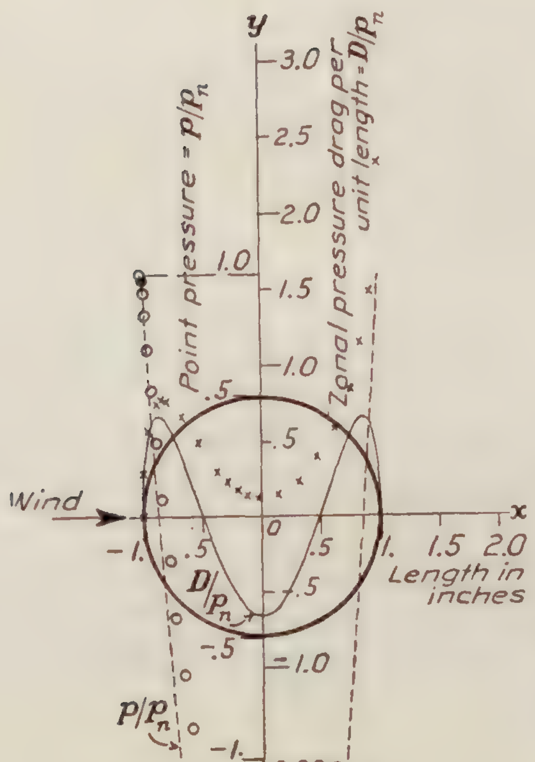


FIG 5.—Pressure and pressure-drag on endless cylinder. Graphs indicate theoretical values; circles indicate pressure p/p_n measured at 40 miles per hour; crosses indicate pressure-drag D/p_n computed from measured pressure

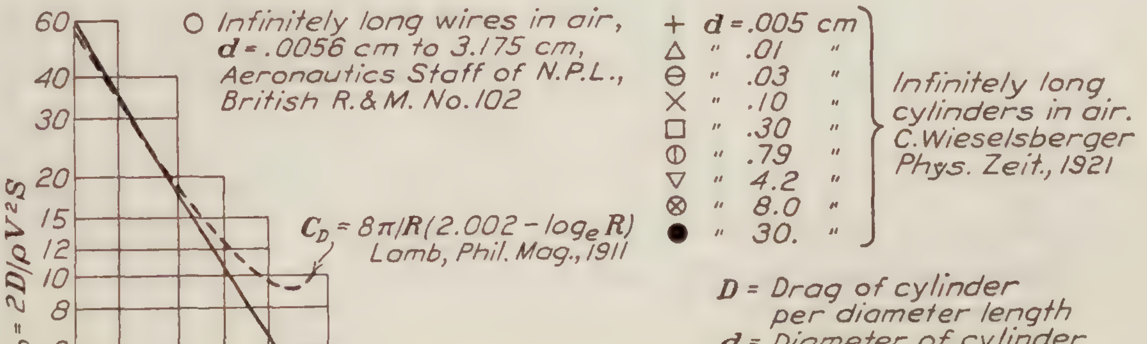


FIG. 6.—Drag coefficient for an endless cylinder in steady translation through a viscous fluid

This is 0, $2a/3$ (max.), 0, $-2a/3$, for $\theta=0°, 30°, 60°, 90°$; and is symmetrical about the equatorial plane $x=0$. In Figure 5, the little crosses give D/p_n for the measured pressures, and show total $D/p_n=2.33a$.

Figure 6 delineates the drag coefficient C_D plotted against $R=2\ aq_0/\nu$, from Wieselsberger's (Reference 1) wind tunnel tests of nine endless cylinders held transverse to the steady flow. The faired line is the graph of

$$C_D=9.4R^{-.8}+1.2, \tag{10}$$

an empirical equation devised by the present writer.

For very low values of R, Lamb derives the formula

$$C_D=\frac{8}{(2.002-\log_e R)R}, \tag{11}$$

whose graph in Figure 6 nearly merges with (10) at $R=.3$.

For $15000<R<200000$, Figure 6 gives $C_D=1.2$; hence the drag per unit frontal area is

$$D=1.2p_n, \tag{12}$$

which is 2.4 times that for the sphere, given by (7).

THE ELLIPTIC CYLINDER

An endless elliptic cylinder held transverse to the stream, as shown in Table I, gives for points on x, y and on its surface,

$$q_x=(1-n)q_0, \qquad q_y=(1+m)q_0, \qquad q_t=(1+b/a)q_0 \sin\theta, \tag{13}$$

where m, n are as in Table I. Amidships $q_t=(1+b/a)q_0=2q_0$ for $a=b$, as given by (8). Graphs of (13) are given in Figure 7.

To find a', b' for plotting (13), assume a' and with it as radius strike about the focus an arc cutting y. The cutting point is distant b' from the origin. Otherwise, $b'=\sqrt{a'^2-c^2}$, where $c^2=a^2-b^2=\text{const.}$

With $a/b=4$ one plots p/p_n in Figure 7, as explained for the sphere. The circles give the experimental p/p_n for an endless 2-inch by 8-inch strut, at zero pitch and yaw, in a tunnel wind at 40 miles an hour. The theoretical and measured pressures agree nicely for all points before, abreast, and well behind the cylinder.

Again, $\sin^2\theta=a^2y^2/(b^4+c^2y^2)$, if $c^2=a^2-b^2$. Hence on the model

$$p/p_n=1-q_t^2/q_0^2=1-\frac{(a+b)^2y^2}{b^4+c^2y^2}. \tag{14}$$

This gives the zonal pressure drag, $D=2\int_0^y p\,dy$, per unit length of cylinder, or

$$D/p_n=2y-2(a+b)^2\int_0^y \frac{y^2\,dy}{b^4+c^2y^2}=-4b\,\frac{a+b}{c^2}\,y+2b^2\,\frac{(a+b)^2}{c^3}\tan^{-1}\frac{cy}{b^2}. \tag{15}$$

whose graph, for $a/b=4$, appears in Figure 8. It rises from 0 at the nose to its maximum where $p=0$, then falls to its minimum amidships.

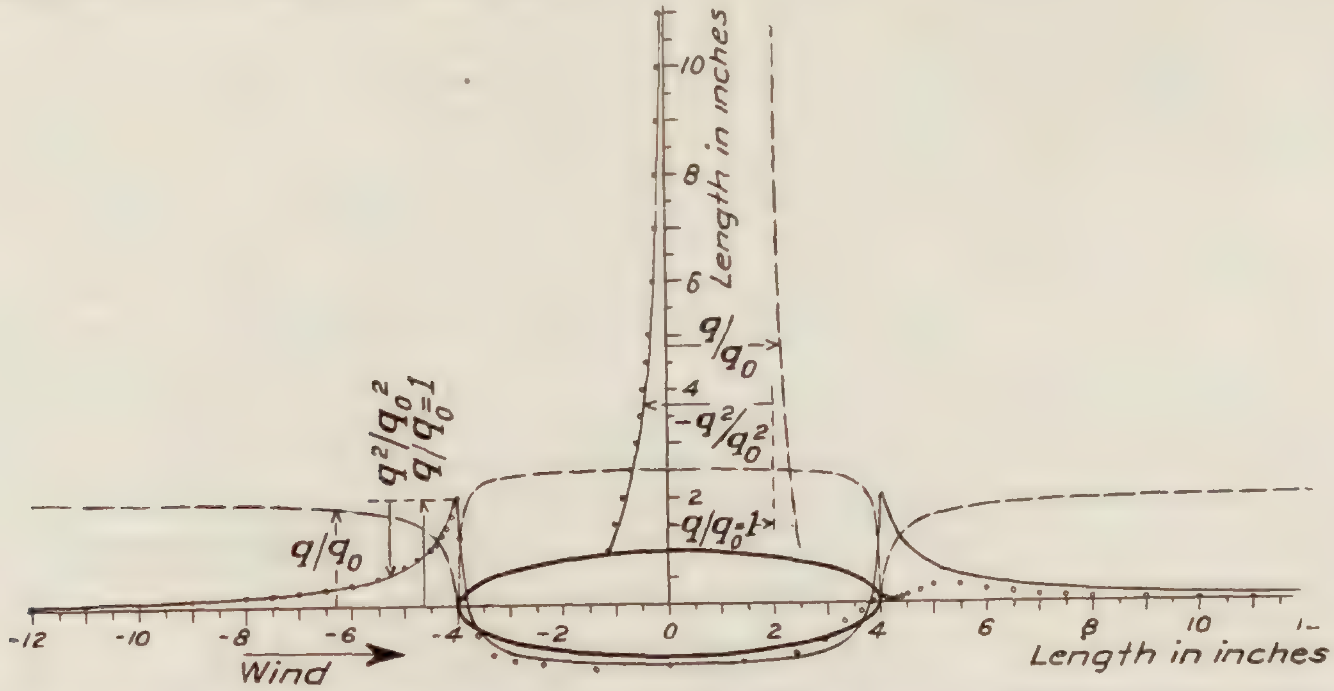


FIG. 7.—Velocity and pressure along axes and over surface of endless elliptic cylinder. Graphs indicate theoretical values; circles indicate pressure measured at 40 miles per hour in 8-foot wind tunnel, United States Navy

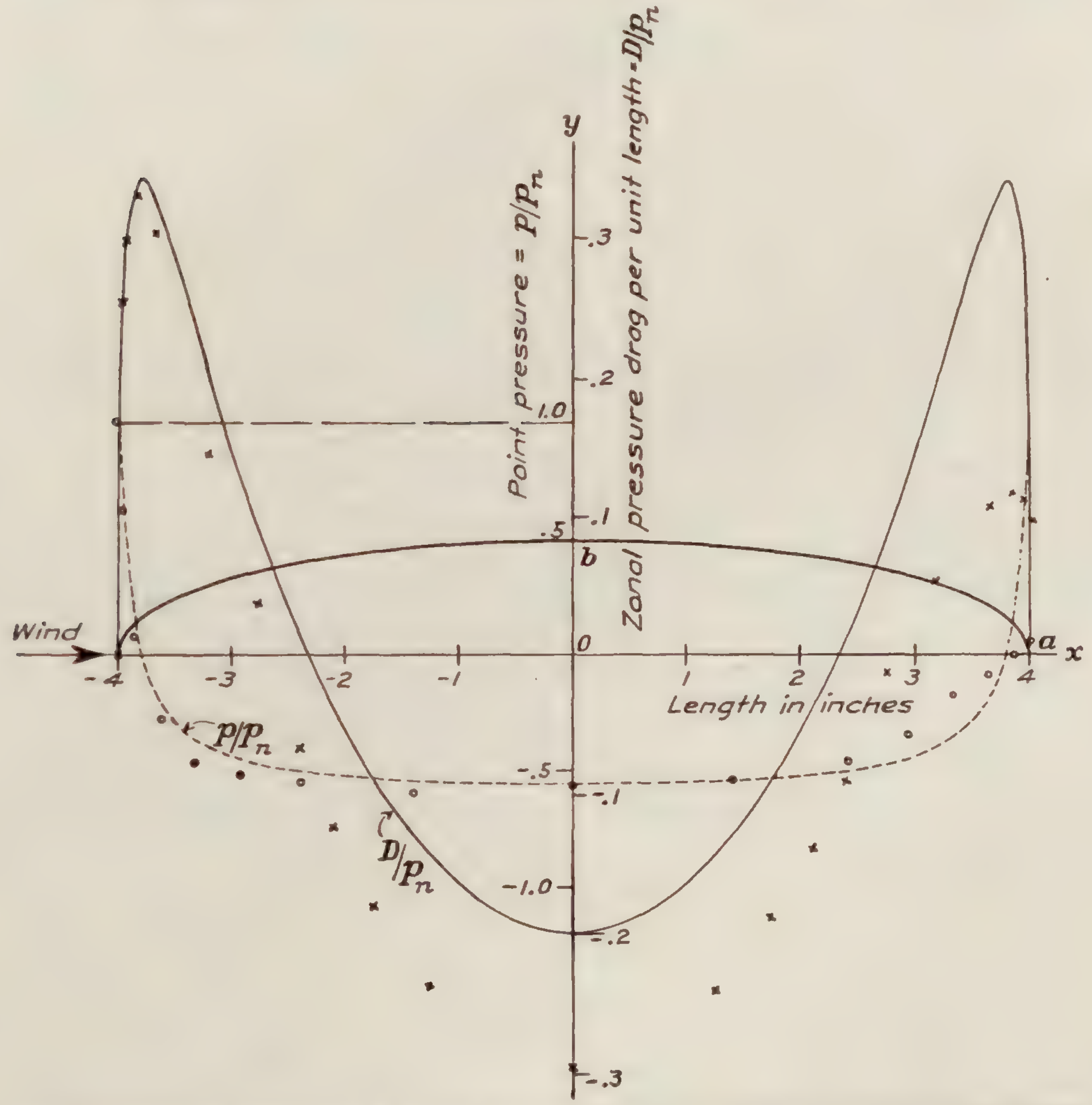


FIG. 8.—Pressure and pressure-drag on endless elliptic cylinder. Graphs indicate theoretical values; circles indicate pressure p/p_n measured at 40 miles per hour; crosses indicate pressure-drag D/p_n computed from measured pressure

Whatever the value of a/b, the whole pressure on the front half is negative or upstream, as for the sphere and round cylinder, and is balanced by the rear drag. For b fixed it decreases indefinitely with b/a.

The crosses marking actual values of D/p_n found in said test show a downstream resultant D. In fact, it is one-third the whole measured drag of pressure plus friction, or one-half the friction drag.

For the cylinder held broadside on, $b>a$ and $a^2-b^2=-c^2$, hence changing c^2 to $-c^2$ under the integral sign of (15), we find

$$D/p_n=-4b\frac{a+b}{c^2}y-b^2\frac{(a+b)^2}{c^3}\log_e\frac{b^2+cy}{b^2-cy}, \tag{16}$$

where now $c^2=b^2-a^2$. With b fixed, the upstream pressure drag on the front half increases with b/a, becoming infinite for a thin flat plate. It is balanced by a symmetrical drag back of the plate.

Such infinite forces imply infinite pressure change at the edges where, as is well known, the velocity can be $q=\sqrt{2p_r/p}=\infty$, in a perfect liquid whose reservoir pressure is $p_r=\infty$. Otherwise viewed, the pressure is p_r at the plate's center (front and back) and decreases indefinitely toward the edges, thus exerting an infinite upstream push on the back and a symmetrical downstream push on the front. In natural fluids no such condition can exist.

THE PROLATE SPHEROID

A prolate spheroid, fixed as in Table I, gives for points on x, y and the solid surface, respectively, the flow speeds

$$q_x=(1-n)q_0, \qquad q_y=(1+m)q_0, \qquad q_t=(1+k_a)\, q_0 \sin\theta, \tag{16}$$

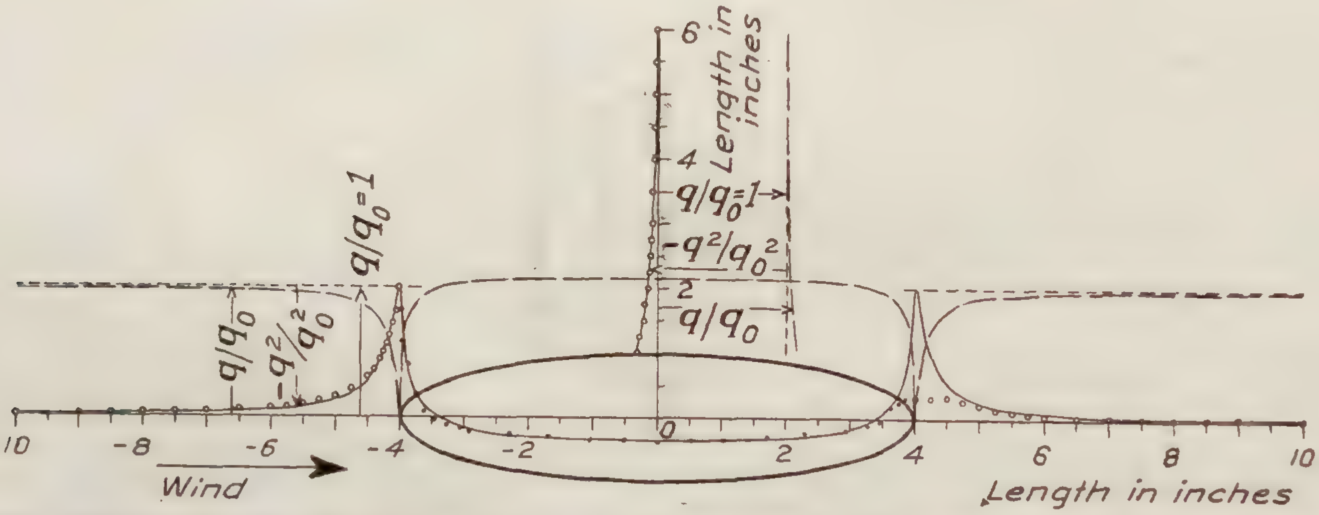


FIG. 9.—Velocity and pressure along axes and over surface of prolate spheroid. Graphs indicate theoretical values; circles indicate pressures measured at 40 miles per hour in 8-foot wind tunnel, United States Navy; dots give pressures found with an equal model in British test, R. and M. No. 600, British Advisory Committee for Aeronautics

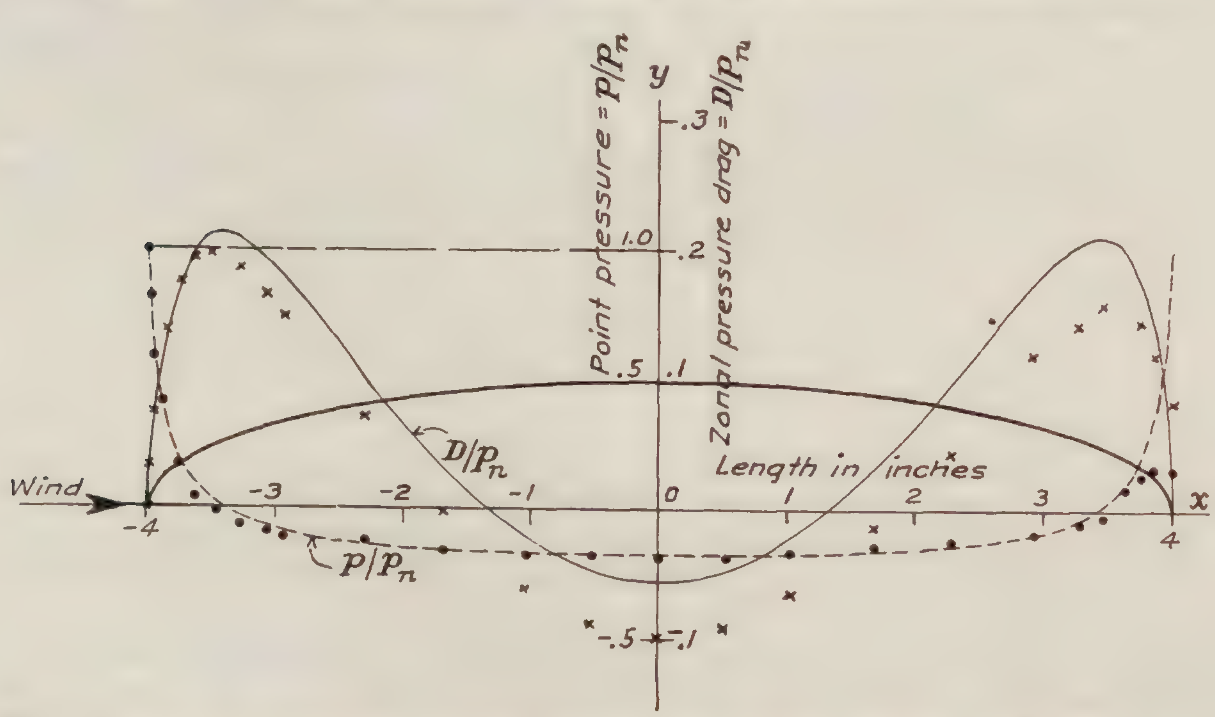


FIG. 10.—Pressure and pressure-drag on prolate spheroid. Graphs indicate theoretical values; dots indicate measured pressure p/p_n from Figure 9; crosses indicate pressure-drag D/p_n computed from measured pressure

where k_a is to be taken from Table II. Graphs of (16) are given in Figure 9, for a model having $a/b=4$, viz., $k_a=0.082$.

For this surface p/p_n plots as in Figure 10. For a 2 by 8 inch brass model values of p/p_n are shown by circles for a test at 40 miles an hour in the United States Navy tunnel; by dots for a like test in a British tunnel. (Reference 2.)

By (16), for points on the surface $p/p_n=1-q_t^2/q_0^2=1-(1+k_a)^2 \sin^2\theta$. From this, since $\sin^2\theta=a^2y^2/(b^4+c^2y^2)$, the zonal pressure drag $\int p.\, 2\,\pi\, y\, dy$ is found. Thus

$$D/p_n=\pi y^2-\frac{\pi a^2}{c^2}(1+k_a)^2 y^2+\frac{\pi a^2 b^4}{c^4}(1+k_a)^2 \log\frac{b^4+c^2y^2}{b^4}. \tag{17}$$

Starting from $y=0$, D/p_n increases to its maximum when $p=0$, or $\sin\theta=1/(1+k_a)$; then diminishes to its minimum for $y=b$. Figure 10 gives the theoretical and empirical graphs of D/p_n for $a/b=4$.

For b fixed the upstream drag on the front half decreases indefinitely with b/a, becoming zero for infinite elongation.

OBLATE SPHEROID

The flow velocity about an oblate spheroid with its polar axis along stream is given by formulas in Table I, and plotted in Figure 11, together with computed values of p/p_n. No determinations of p or D were made for an actual flow. The formula for D/p_n is like (17), except that $c^2=b^2-a^2$, and k_a is larger for the oblate spheroid, as seen in Table II. For b fixed the upstream drag on the front half increases indefinitely with b/a.

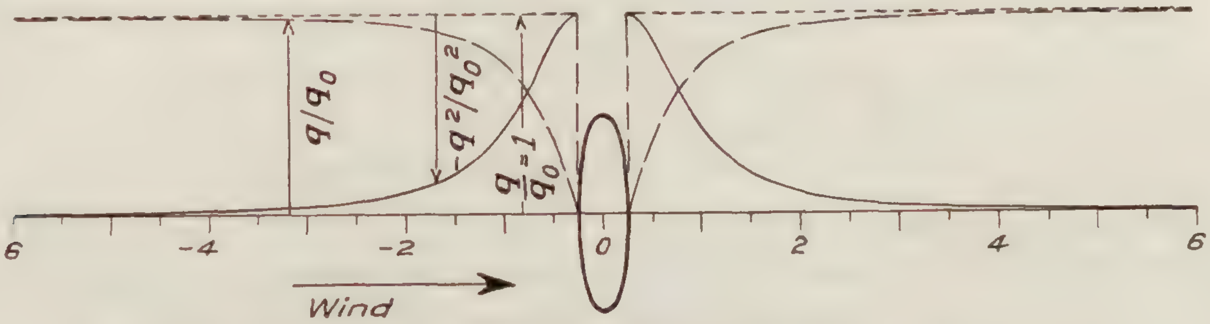


FIG. 11.—Theoretical velocity and pressure along x axis of oblate spheroid. Diameter/thickness=4

CIRCULAR DISK

The theoretical flow speeds and superpressures for points on the axis of a circular disk fixed normal to a uniform stream of inviscid liquid are plotted in Figure 12, without comparative data from a test. One notes that the formulas are those for an oblate spheroid with eccentricity $e=1$.

For $1500<q_0\, a/\nu<500000$, Wieselsberger (Reference 3) finds for the air drag of a thin normal disk, of area S,

$$D=1.1\, p_n S, \tag{18}$$

or 2.2 times that for a sphere. For aq_0/ν extremely small, theory gives

$$D=5.1\,\pi\,\mu\, a\, q_0, \tag{19}$$

as is well known. Test data for a complete graph, including these extremes, are not yet available.

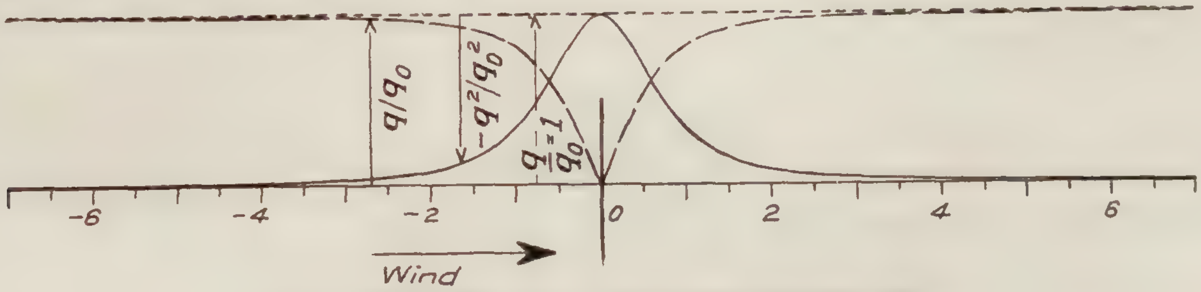


FIG. 12.—Theoretical pressure and velocity along axis of disk

REGIONS OF EQUAL SPEED

In the flow field q, p are constant where $q_t^2+q_n^2=$ constant, viz. where

$$q^2/q_o^2=(1+m)^2\sin^2\theta+(1-n)^2\cos^2\theta=\text{const.} \tag{20}$$

In particular for the region $q=q_o$, this becomes

$$\tan^2\theta=\frac{n}{m}\,\frac{2-n}{2+m}=\frac{a'^4}{b'^4}\tan^2\beta^{*} \tag{21}$$

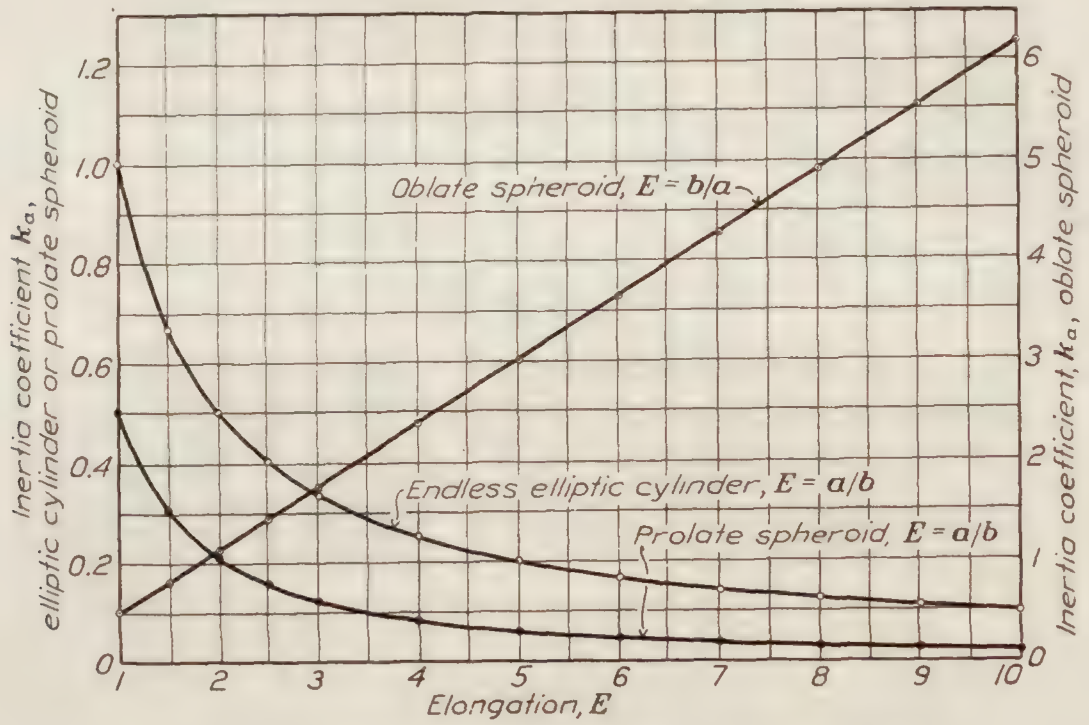


FIG. 13.—Inertia coefficient vs. elongation. Plotted from Table II

which applies to all the quadrics in Table I. Clearly $\tan\,\theta=0$ for $n=2$; $\tan^2\theta=n/m$ for m, $n=0$, viz. for all distant points of (21). For these points the normal to any confocal ellipse lies along the radius vector and asymptote of (21), as seen in Figures 14 to 17.

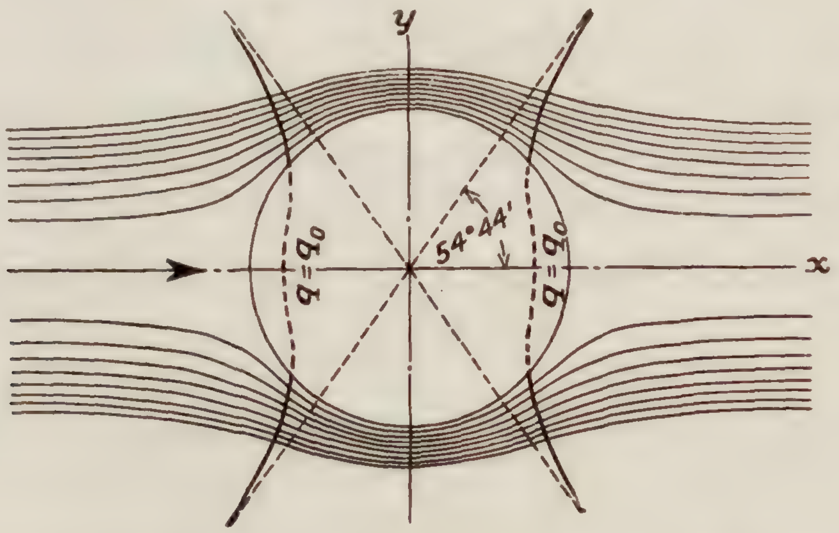


FIG. 14.—Lines of steady flow, lines of constant speed and pressure, for infinite frictionless liquid streaming past a sphere

For the sphere $n=2m=a^3/r^3$; hence (21) becomes

$$\tan^2\theta=2\,\frac{2r^3-a^3}{2r^3-.5a^3} \tag{22}$$

where $r=a'=\sqrt{x^2+y^2}$. The form of this is depicted in Figure 14.

---

[*] $\tan\beta=y/x$ is the slope of a radial line through the point (x, y) where (21) cuts a confocal curve $a'b'$, of Table I. Knowing a', b', β, to locate (x, y) draw across the radial line an arc of $a'b'$ by sliding along the x, y axes a straightedge subdivided as in the ellipsograph. The operation is rapid and easy.

For a round cylinder $n=m=a^2/r^2$; hence

$$\tan^2\theta=\frac{2r^2-a^2}{2r^2+a^2} \text{ or, } 2r^2=a^2 \sec 2\theta, \tag{23}$$

which is the section of a hyperbolic cylinder, as in Figure 15.

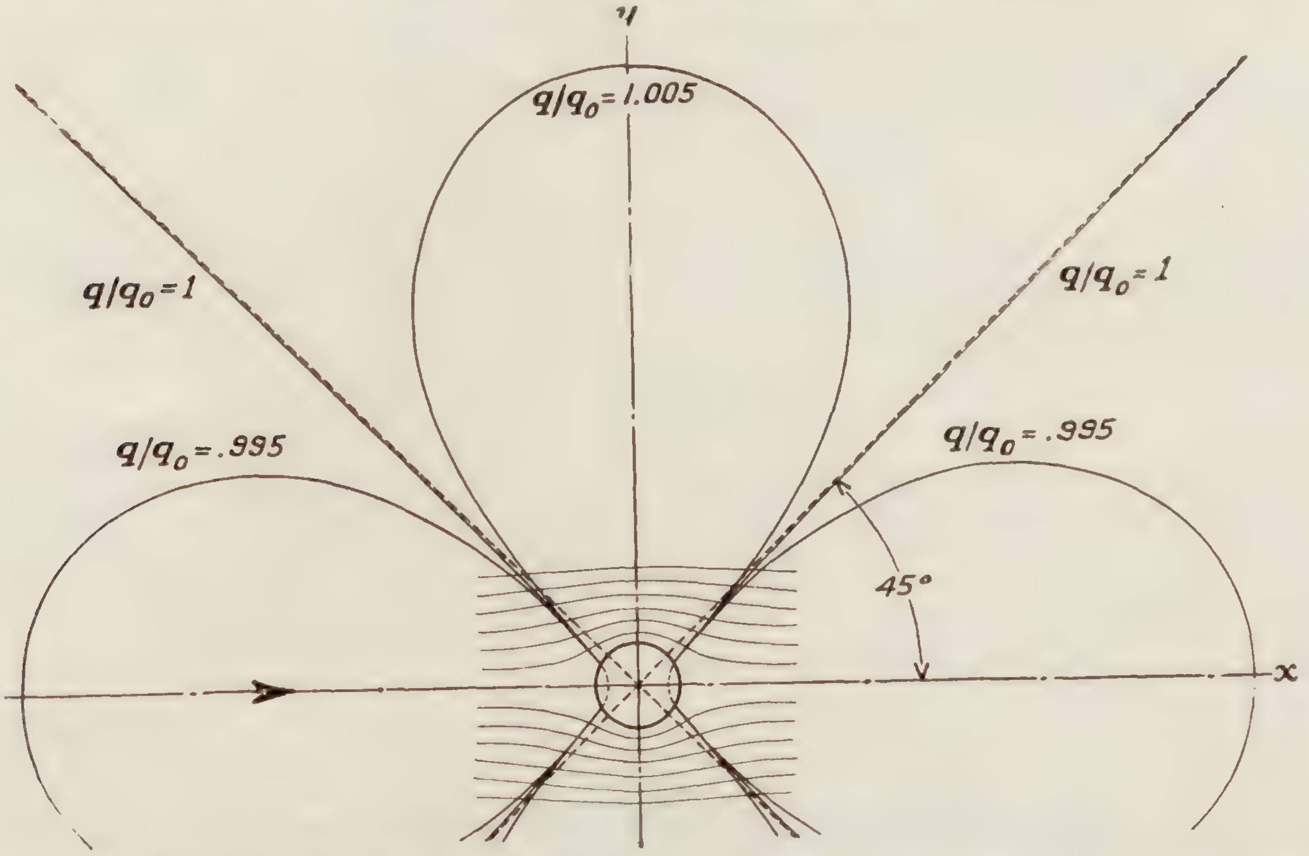


FIG. 15.—Lines of steady flow, lines of constant speed and pressure, for infinite frictionless liquid streaming across endless round cylinder

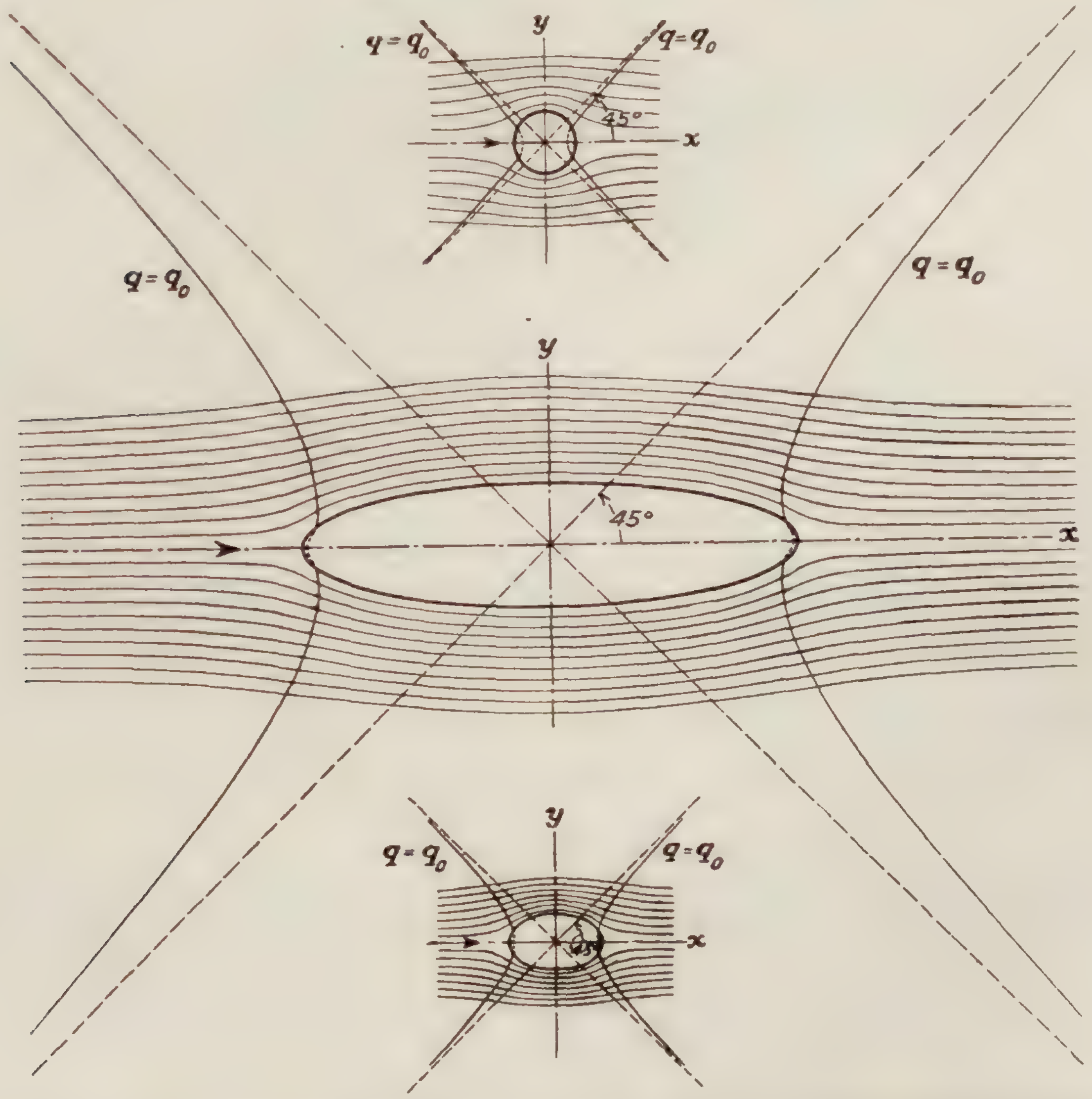


FIG. 16.—Lines of steady flow, lines of constant speed and pressure, for infinite frictionless liquid streaming across endless elliptic cylinder

A plot of (21) for an elliptic cylinder, fixed as shown in Table I, is given in Figure 16; for a prolate spheroid in Figure 17.

Besides the region (21), having $q=q_o$, it is useful to know the limit of perceptible disturbance say where $q^2/q_o^2=1\pm.01$. This in (20) gives

$$(1+m)^2\sin^2\theta+(1-n)^2\cos^2\theta=1\pm.01, \tag{24}$$

which applies to all the quadrics here studied. Hence

$$\tan^2\theta=\frac{n}{m}\,\frac{2-n}{2+m}\pm\frac{0.01}{m(2+m)\cos^2\theta}, \tag{25}$$

A graph of (25) for a round cylinder is shown in Figure 15. Like plots for the other quadrics

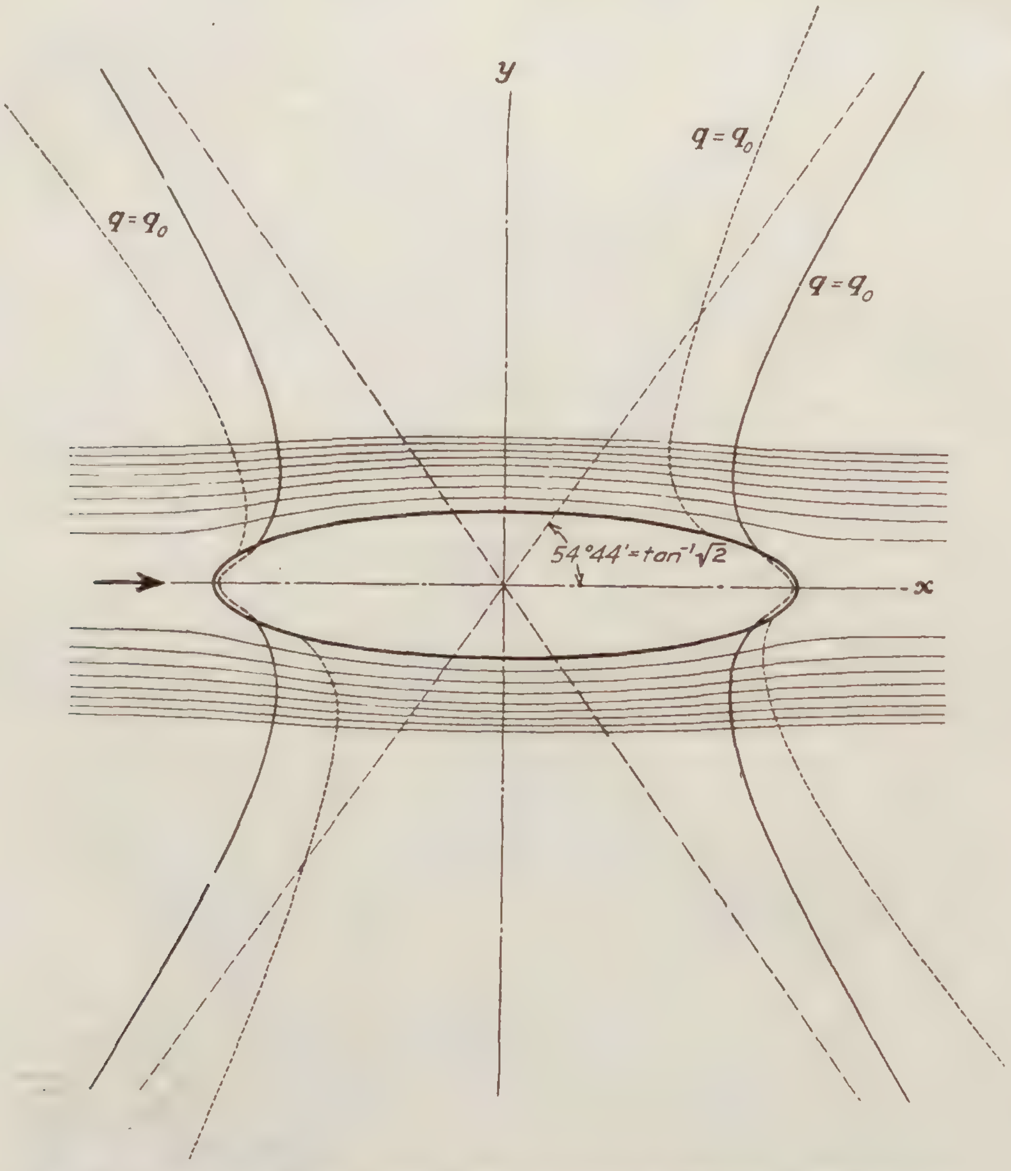


FIG. 17.—Lines of steady flow, lines of constant speed and pressure, for infinite frictionless liquid streaming past a prolate spheroid. Full-line curve $q=q_o$ refers to stream parallel to x; dotted curve $q=q_o$ refers to stream inclined 10° to x

If in (20) a series of constants be written for the right member, the graphs compose a family of lines of equal velocity and pressure, covering the entire flow field. Rotating Figures 14, 17 about x gives surfaces of $q=q_o$.

COMPARISON OF SPEEDS

Before all the fixed models the flow speed is q_o at a great distance and 0 at the nose; abreast of them it is q_o at a distance, and $(1+k_a)q_o$ amidships.

The flux of $q-q_o$ through the equatorial plane obviously must equal q_oS where S is the body's frontal area. Hence two bodies having equal equators have the same flux q_oS, and the same average superspeed or average $q-q_o$. But the longer one has the lesser midship speed;

hence its outboard speed wanes less rapidly with distance along y. A like relation obtains along x from the nose forward. These relations are shown in the velocity graphs of Figures 18 and 19. A figure similar to 18, including many models, is given in Reference 4.

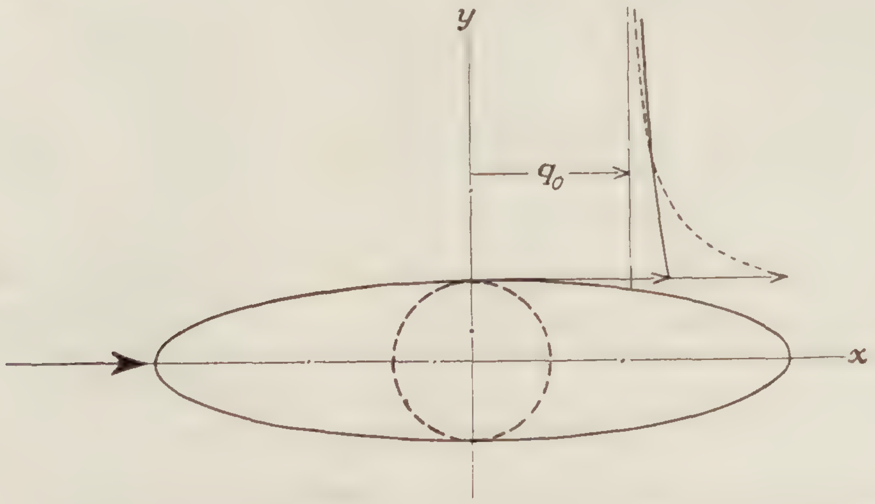


FIG. 18.—Superposed graphs of flow speed abreast of endless round and elliptic cylinders of same thickness fixed transverse to an infinite stream of inviscid liquid. At great distance flow speed is q_o

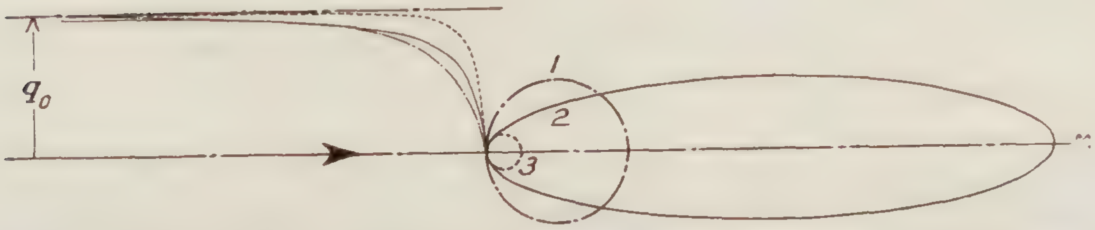


FIG. 19.—Superposed graphs of axial flow speed before three endless cylinders 1, 2, and 3 (3 osculating 2), each fixed transverse to an infinite stream of inviscid liquid. At great distance flow speed is q_o

COMPARISON OF PRESSURES

The foregoing speed relations determine those of the pressures. The nose pressures all are $p_n = \rho q_o^2/2$; the midship ones are $p = p_n - (1+k_a)^2 p_n$. The drag on the front half of the model is upstream for all the quadrics here treated; it increases with the flatness, as one proves by (15), (17), and is infinite for the normal disk and rectangle.

APPLICATION OF FORMULAS

The ready equations here given, aside from their academic interest in predicting natural phenomena from pure theory, are found useful in the design of air and water craft. The formula for nose pressure long has been used. That for pressure on a prolate spheroid, of form suitable for an airship bow, is so trustworthy as to obviate the need for pressure-distribution measurements on such shapes. The same may be said of the fore part of well-formed torpedoes deeply submerged. The computations for stiffening the fore part of airship hulls can be safely based on theoretical estimates of the local pressures. The velocity change, well away from the model, especially forward of the equatorial plane, can be found more accurately by theory than by experiment. The equation (21) of undisturbed speed shows where to place anemometers to indicate, with least correction, the relative speed of model and general stream.

REFERENCES

1. WIESELSBERGER, C.: Physicalische Zeitschrift, vol. 22. 1921.
2. JONES, R., and WILLIAMS, D. H.: The distribution of pressure over the surface of airship model U. 721, together with a comparison with the pressure over a spheroid. Brit. Adv. Com. for Aeron. Reports and Memoranda No. 600. 1919.
3. WIESELSBERGER, C.: Physicalische Zeitschrift, vol. 23. 1922.
4. TAYLOR, D. W.: Speed and Power of Ships, gives a figure similar to 18 but including more models. 1910.

SYMBOLS USED IN TEXT

x, y	Cartesian coordinates; also axes of same.
r, β	Polar coordinates.
α	Angle of attack of uniform stream.
s	Length of arc, increasing with β.
θ	Inclination to x of normal to confocal curves in Table I.
φ	Velocity function.
ψ	Stream function.
q	Resultant velocity at any point of fluid.
q_o	Velocity of distant fluid (parallel to x axis).
q_x, q_y	Velocity at points on x and y axes (parallel to x axis).
q_t	Velocity along confocal surface or model surface.
q_n	Velocity normal to confocal surface.
ρ	Density of fluid.
μ	Viscosity.
ν	Kinematic viscosity.
p_n	Nose pressure $=\rho\, q_o^2/2$.
p_o	Pressure in distant fluid.
p	Superstream pressure anywhere.
D	Zonal pressure drag $=\int p\,dy\,dz$.
D	Whole drag.
S	Frontal area of model.
C_D	Drag coefficient $=D'p_nS$.
R	Reynolds number.
a	Radius of sphere, cylinder.
a, b	Semiaxes of ellipse.
a', b'	Semiaxes of confocal ellipse.
e	Eccentricity of ellipse.
e'	Eccentricity of confocal ellipse.
c	Focal distance $=ae=a'e'=\sqrt{a^2-b^2}$
k_a	Inertia factor (Table II).
m, n, m_s	Quantities defined in Tables I, II.
ϵ	Colatitude (see equation 30).

TABLE I

Flow functions for simple quadrics fixed in a uniform stream of speed q_o along x positive

Symbol definitions	Form of quadric	Value of functions at any confocal surfaces of semiaxes a', b'		
		Velocity function φ	Stream function ψ	Component velocities q_t, q_n
See diagram A (fig. 20)	Sphere	$\varphi=-(1+m)\,q_ox$, where $m=\frac{a^3}{2a'^3}$	$\psi=-\frac{1}{2}(1-n)\,q_oy^2$, where $n=\frac{a^3}{a'^3}$	Differentiation along arc s of either figure gives: $q_t=\frac{\partial\varphi}{\partial x}\frac{dx}{ds}=(1+m)\,q_o \sin\theta$, valid for all the figures; $q_n=\frac{\partial\psi}{\partial y}\frac{dy}{ds}=-(1-n)\,q_o \cos\theta$, for the cylinders; $q_n=\frac{1}{y}\frac{\partial\psi}{\partial y}\frac{dy}{ds}=-(1-n)\,q_0\cos\theta$, for the axial surfaces; viz., sphere, spheroids, disk. For $a', b'=a, b$, Table II gives m_s; whence $q_t=(1+m_s)\,q_o\sin\theta$, as the flow velocity on a fixed quadric surface. $q_n=\pm 0$ for disk, since $n=1$ *Remark*—both q_t q_n can be derived from either φ or ψ'. If $q_t, q_n=$ max. q_t, q_n on $a'b'$, at any other point thereof $q_t=\bar{q}_t \sin\theta$, $q_n=\bar{q}_n \cos\theta$
	Circular cylinder	$\varphi=-(1+m)\,q_ox$, $m=\frac{a^2}{a'^2}$	$\psi=-(1-n)\,q_oy$, $n=\frac{a^2}{a'^2}$	
See diagram B (fig. 20)	Elliptic cylinder	$\varphi=-(1+m)\,q_ox$, $m=\frac{b}{a'}\frac{a+b}{a'+b'}$	$\psi=-(1-n)\,q_oy$, $n=\frac{b}{b'}\frac{a+b}{a'+b'}$	
	Prolate spheroid $e=\frac{1}{a}\sqrt{a^2-b^2}$	$\varphi=-(1+m)\,q_ox$, $m=-\frac{\log_e\frac{1+e'}{1-e'}-2e'}{\log_e\frac{1+e}{1-e}-\frac{2e}{1-e^2}}$	$\psi=-\frac{1}{2}(1-n)\,q_oy^2$, $n=\frac{\log_e\frac{1+e'}{1-e'}-\frac{2e'}{1-e'^2}}{\log_e\frac{1+e}{1-e}-\frac{2e^2}{1-e^2}}$	
See diagram C (fig. 20)	Oblate spheroid $e=\frac{1}{b}\sqrt{b^2-a^2}$	$\varphi=-(1+m)\,q_ox$, $m=-\frac{\frac{e'b'}{a'}-\sin^{-1}e'}{\frac{ea}{b}-\sin^{-1}e}$	$\psi=-\frac{1}{2}(1-n)\,q_oy^2$, $n=\frac{\frac{e'a'}{b'}-\sin^{-1}e'}{\frac{ea}{b}-\sin^{-1}e}$	
	Circular disk $a=0, e=1$	$\varphi=-(1+m)\,q_ox$, $m=\frac{2}{\pi}\left(\frac{b}{a'}-\sin^{-1}e'\right)$	$\psi=-\frac{1}{2}(1-n)\,q_oy^2$, $n=-\frac{2}{\pi}\left(\frac{a'b}{b'^2}-\sin^{-1}e'\right)$	

φ, ψ, in elliptic coordinates, can be found in textbooks; e. g., §§ 71,105,108, Lamb's Hydrodynamics, 4th Ed.

TABLE II

Inertia factors k_a* for quadric surfaces in steady translation along axis a in Figure 20

Elongation E	Elliptic cylinder, $E=a/b$ $k_a=\frac{b}{a}$	Prolate spheroid $E=a/b$ $k_a=-\frac{\log_e\frac{1+e}{1-e}-2e}{\log_e\frac{1+e}{1-e}-\frac{2e}{1-e^2}}$	Oblate spheroid $E=b/a$ $k_a=-\frac{eE^2-E\sin^{-1}e}{e-E\sin^{-1}e}$
1. 00	1. 000	0. 500	0. 500
1. 50	. 667	. 305	. 803
2. 00	. 500	. 209	1. 118
2. 50	. 400	. 157	1. 428
3. 00	. 333	. 121	1. 742
4. 00	. 250	. 082	2. 379
5. 00	. 200	. 059	3. 000
6. 00	. 167	. 045	3. 642
7. 00	. 143	. 036	4. 279
8. 00	. 125	. 029	4. 915
9. 00	. 111	. 024	5. 549
10. 00	. 100	. 021	6. 183
∞	. 000	. 000	∞

*In this table $k_a=m_a$ of Table I, viz, the value of m when $a', b'=a, b$. Lamb (R. and M. No. 623, Brit. Adv. Com. Aeron.) gives the numerical values in the third column above. For motion of elliptic cylinder along b axis inertia factor is $k_b=a/b$.

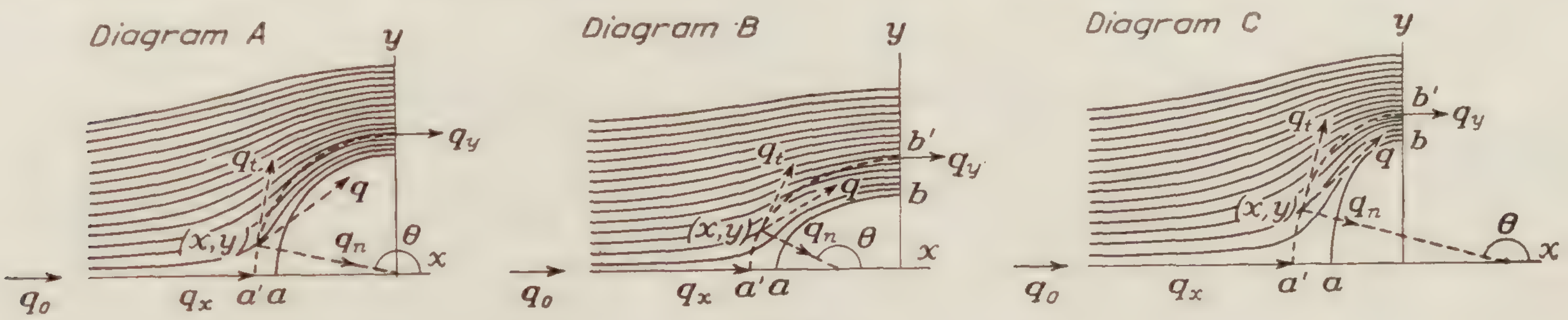


FIG. 20

VELOCITY AND PRESSURE IN OBLIQUE FLOW [2]

PRINCIPLE OF VELOCITY COMPOSITION

A stream q_0 oblique to a model can be resolved in chosen directions into component streams each having its individual velocity at any flow point, as in Figure 21. Combining the individuals gives their resultant, whence p is found.

VELOCITY FUNCTION

Let a uniform infinite stream q_0 of inviscid liquid flowing past a fixed ellipsoid centered at the origin have components U, V, W along x, y, z, taken parallel, respectively, to the semiaxes, a, b, c; then we find the velocity potential φ for q_0 as the sum of the potentials φ_a, φ_b, φ_c for U, V, W.

In the present notation textbooks prove, for any point (x, y, z) on the confocal ellipsoid $a'\ b'\ c'$,

$$\varphi_a=-(1+m_a)Ux, \tag{26}$$

and give as constant for that surface

$$m_a=abc\left(1-abc\int_a^\infty\frac{da'}{a'^{\,2}\,b'\,c'}\right)^{-1}\int_\lambda^\infty\frac{da'}{a'^{\,2}\,b'\,c'}\ {}^{*} \tag{27}$$

the multiplier of $\int_\lambda^\infty$ being constant for the model, and $\lambda=a'^{\,2}-a^2$. Adding to (26) analogous values of φ_b, φ_c gives

$$\varphi=-(1+m_a)Ux-(1+m_b)Vy-(1+m_c)Wz\equiv-(1+m)q_0h, \tag{28}$$

---

[2] This brief treatment of oblique flow was added by request after the preceding text was finished.

* Simple formulas for this integral and the corresponding b, c ones, published by Greene, R. S. Ed. 1833, are given by Doctor Tuckerman in Report No. 210 of the National Advisory Committee for Aeronautics for 1925. Some ready values are listed in Tables III, IV.

where h is the distance of (x, y, z) from the plane $\varphi=0$, and m_a, m_b, m_c, m are generalized inertia coefficients of $a'\ b'\ c'$ for the respective streams U, V, W, q_0. For the model itself the inertia coefficients usually are written k_a, k_b, k_c, k. The direction cosines of h are

$$L=\frac{1+m_a}{1+m}\frac{U}{q_0},\quad M=\frac{1+m_b}{1+m}\frac{V}{q_0},\quad N=\frac{1+m_c}{1+m}\frac{W}{q_0},\tag{29}$$

as appears on dividing (28) by $(1+m)q_0$, the resultant of $(1+m_a)U$, $(1+m_b)V$, $(1+m_c)W$.

EQUIPOTENTIALS AND STREAMLINES

On $a'\ b'\ c'$ the plane sections $\varphi=$ constant are equipotential ellipses parallel to the major section $\varphi=0$, and dwindling fore and aft to mere points, which we call stream poles, where the plane (28) is tangent to $a'\ b'\ c'$. If ϵ is the angle between any normal to $a'\ b'\ c'$ and the polar normal, whose direction cosines are L, M, N, we call the line $\epsilon=$ const. a line of stream latitude. Thus ϵ is the colatitude or obliquity of a surface element of $a'\ b'\ c'$. The line $\epsilon=90°$ is the stream equator. This latter marks the contact of a tangent cylinder parallel to the polar normal, viz, perpendicular to the plane (28), as in Figure 22. If l, m, n are the direction cosines of any normal to $a'\ b'\ c'$

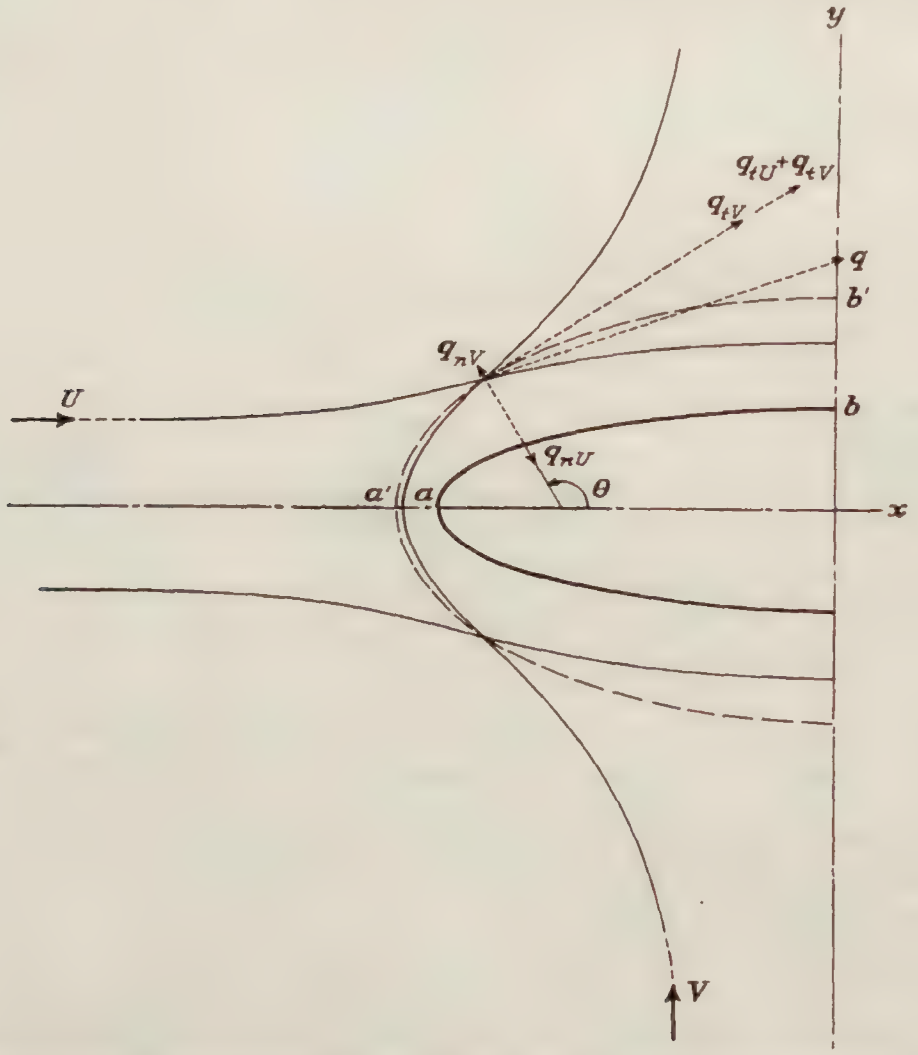


FIG. 21.—Superposition of streamline velocities for component plane flows parallel to axes of elliptic cylinder

$$\cos\epsilon=lL+mM+nN.\tag{30}$$

Since the streamlines all cut the equipotentials squarely,[3] the polar streamline must run continuously normal to the family of confocal ellipsoids $a'\ b'\ c'$. Hence it forms the intersection of a pair of confocal hyperboloids, and at infinity asymptotes a line parallel to q_0 through the origin. This straight line may be called the stream axis. Its equation is $x:y:z=U:V:W$.

---

[3] On the model, therefore, the streamlines are longitude lines, viz. orthogonals to the latitude lines.

COMPONENT VELOCITIES

At any point of any confocal surface $a'\ b'\ c'$ the streamline velocity q, perpendicular to the equipotential ellipse there, has components q_n, q_t, respectively, along the surface normal n and the tangent s in the plane of q and n. By (28) we have

$$q_t=\frac{\partial\varphi}{\partial h}\frac{dh}{ds}=\bar{q}_t \sin \epsilon, \tag{31}$$

where $-\partial\varphi/\partial h=(1+m)q_0\equiv\bar{q}_t=\text{max. } q_t$, is the equatorial velocity. By (26) the inward normal velocity due to φ_a is

$$-\frac{\partial}{\partial_n}(1+m_a)Ux=-l(1-n_a)U, \tag{32}$$

n_a being constant on $a'\ b'\ c'$, as may be shown. Similarly, φ_b, φ_c contribute $-m(1-n_b)V, -n(1-n_c)W$; hence the whole normal component is

$$q_n=-l(1-n_a)U-m(1-n_b)V-n(1-n_c)W=\bar{q}_n \cos \epsilon, \tag{33}$$

where $\bar{q}_n=[(1-n_a)^2U^2+(1-n_b)^2V^2+(1-n_c)^2W^2]^{.5}=\text{max. } q_n$ is the normal velocity at the stream poles. Some values of n_a, n_b are given in Tables I, III. One also may find (33) as the normal derivative of (28).

We now state (28): At any point of $a'\ b'\ c'$ the velocity potential equals $\bar{q}_t h$, the equatorial speed times the distance from the plane of zero potential. Similarly (31) (33) state: At any point of $a'\ b'\ c'$ the tangential speed ($\bar{q}_t \sin \epsilon$) equals the equatorial speed times the sine of the obliquity; the normal speed ($q_n \cos \epsilon$) equals the polar speed times the cosine of the obliquity. This theorem applies to all the confocals, even at the model where $q_n=0$.[4]

Incidentally the normal flux through $a'\ b'\ c'$ is $\int \bar{q}_n \cos \epsilon \cdot dS=\bar{q}_n \int dS_\phi$, where S_ϕ is the projection of S on the plane of $\phi=\text{const.}$ and equals the cross section of the tangent cylinder. The whole flux through $a'\ b'\ c'$ is therefore zero, as should be.

POLAR STREAMLINE

Some of the foregoing relations are portrayed in Figure 22 for a case of plane flow. Noteworthy is the polar streamline or hyperbola. Starting at infinity parallel to q_0, the polar filament runs with waning speed normally through the front poles of the successive confocal surfaces; abuts on the model at its front pole, or stop point; spreads round to the rear pole; then accelerates downstream symmetric with its upstream part. Its equation $q_t=0=\partial\phi/\partial s$ can be written from (28)

$$q_t=(1+m_a)U \sin \theta-(1+m_b)V \cos \theta=0, \text{ or } \tan \theta=\frac{1+m_b}{1+m_a}\frac{V^*}{U} \tag{34}$$

This asymptotes the stream axis $y/x=V/U$; for at infinity m_a, $m_b=0$, and $\tan \theta=V/U$. Plane-flow values of m_a, m_b are given in Tables I, III.

All the confocal poles are given by (34); those of the model are at the stops where

$$\tan \theta=\frac{1+k_a}{1+k_b}\frac{V}{U}=\frac{a^2}{b^2}\frac{y}{x}. \tag{37}$$

Thus on an elliptic cylinder they are where $y/x=b^3/a^3.\ V/U$; on a thin lamina they are at $x=\pm c \cos \alpha$, as given in the footnote. Tables II, IV give values of k_a, k_b.

---

[4] An analogous theorem obtains also for any other uniform steady stream, say of heat or electricity, that has zero normal component at the boundary ellipsoid and zero concentration in the flow field.

[*] To graph (34) we may use the known relations.

$$\tan \theta=\frac{a'^2}{b'^2}\frac{y}{x}=\frac{a'}{b'}\tan \alpha, \tag{35}$$

where $\tan \alpha=V/U$ is the slope of q_0 or the asymptote to (34). Thus (34) becomes $a'/b'=(1+m_b)/(1+m_a)$, which with the tabulated values of m_a, m_b, reduces to

$$\frac{x}{c^2 \cos^2 \alpha}-\frac{y^2}{c^2 \sin^2 \alpha}=1, \tag{36}$$

a hyperbola whose semiaxes are $c \cos \alpha$, $c \sin \alpha$, c being the focal distance. In this treatment $x=a' \cos \alpha$, $y=b' \sin \alpha$, α being a fixed eccentric angle of the successive confocal elipses.

Each angle of attack has its own flow pattern; each its polar streamline given by (34). A close-graded family of confocal ellipses and hyperbolas therefore portrays all the poles and polar streamlines in the plane *ab* for all angles of attack. The family can be written

$$x=a' \cos \alpha, \qquad y=b' \sin \alpha. \tag{38}$$

Thus, giving a', b' a set of fixed values, then α a set, we have the confocal families

$$\frac{x^2}{a'^2}+\frac{y^2}{b'^2}=1. \qquad \frac{x^2}{c^2 \cos^2 \alpha}-\frac{y^2}{c^2 \sin^2 \alpha}=1. \tag{39}$$

the first being ellipses, the second hyperbolas like (36) below.

Similarly, the locus $q_n=0$, or $q=\bar{q}_t$, is written from (33). With $W=0$,

$$\tan \theta=-\frac{1-n_a}{1-n_b}\frac{U}{V}. \tag{40}$$

Its discussion is of minor interest.

DRAG AND MOMENT

Formulas for the pressure p all over the simple quadrics here treated are well known, for oblique as well as axial flow, and serve to find the drag and moment. For uniform flow the resultant drag is zero; its zonal parts can be found as heretofore. The moment about z is the surface integral of $p(y\, dy\, dz-x\, dx\, dz)$, and generally is not zero.

REGIONS OF EQUAL SPEED ABOUT OBLIQUE MODELS

Compounding the velocities (31), (33) at any point in the *ab* plane, as in Figure 22, gives for q constant

$$q^2=[(1+m_a)U \sin \theta-(1+m_b)V \cos \theta]^2+[(1-n_a)U \cos \theta+(1-n_b)V \sin \theta]^2=\text{const.} \tag{41}$$

In particular for $q^2=U^2+V^2$ (41) gives

$$\tan \theta=\frac{K}{B}(A\pm\sqrt{BC+A^2})=\frac{a'^2}{b'^2}\tan \beta. \tag{42}$$

where $K=V/U$, and

$$A=(1+m_a)(1+m_b)-(1-n_a)(1-n_b), B=m_a(2+m_a)-n_b(2-n_b)K^2, C_D=\frac{n_a(2-n_a)}{K^2}-m_b(2+m_b).$$

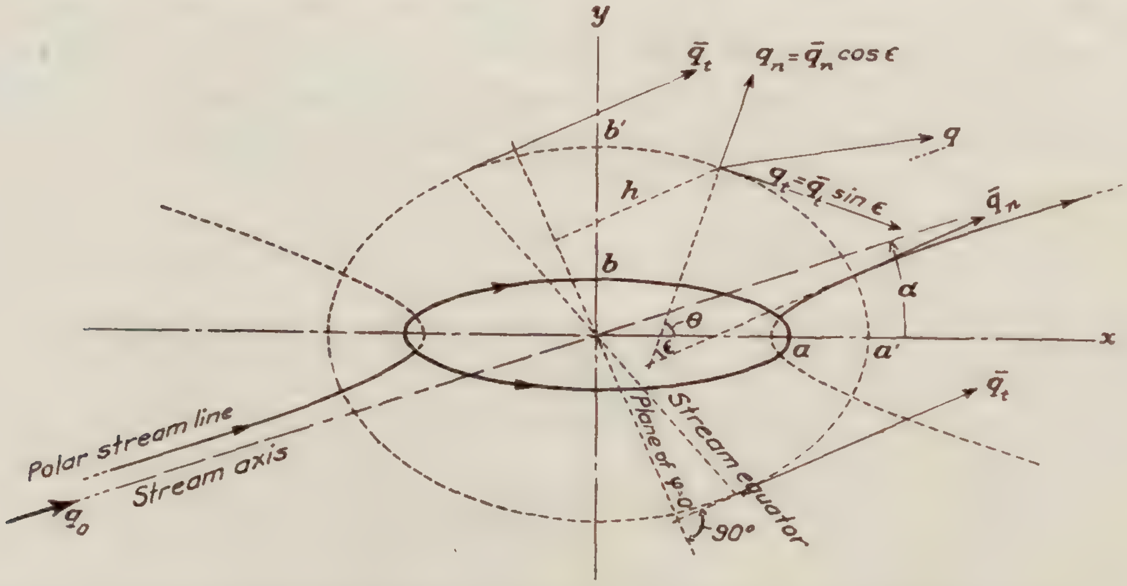


FIG. 22.—Polar streamline and component velocities for uniform stream of inviscid liquid about oblique elliptic cylinder

For an elliptic cylinder, as is well known.

$$m_a=\frac{b}{a'}\frac{a+b}{a'+b'}, \qquad n_a=\frac{b}{b'}\frac{a+b}{a'+b'}, \qquad m_b=\frac{a}{b'}\frac{a+b}{a'+b'}, \qquad n_b=\frac{a}{a'}\frac{a+b}{a'+b'},$$

which determines A, B, C, and thence β in terms of a' b'. Thus, for an endless elliptic cylinder of semiaxes $a=4$, $b=1$, yawed 10° to the stream, i. e., $V/U=\tan 10°=.1763$, the graph of (42) has the form shown full line in Figure 23. This graph takes the dotted form when $V=0$, $q_o=U$.

For a prolate spheriod of semiaxes $a=4$, $b=1$, yawed 10°, the graph of (42) is shown in Figure 17.

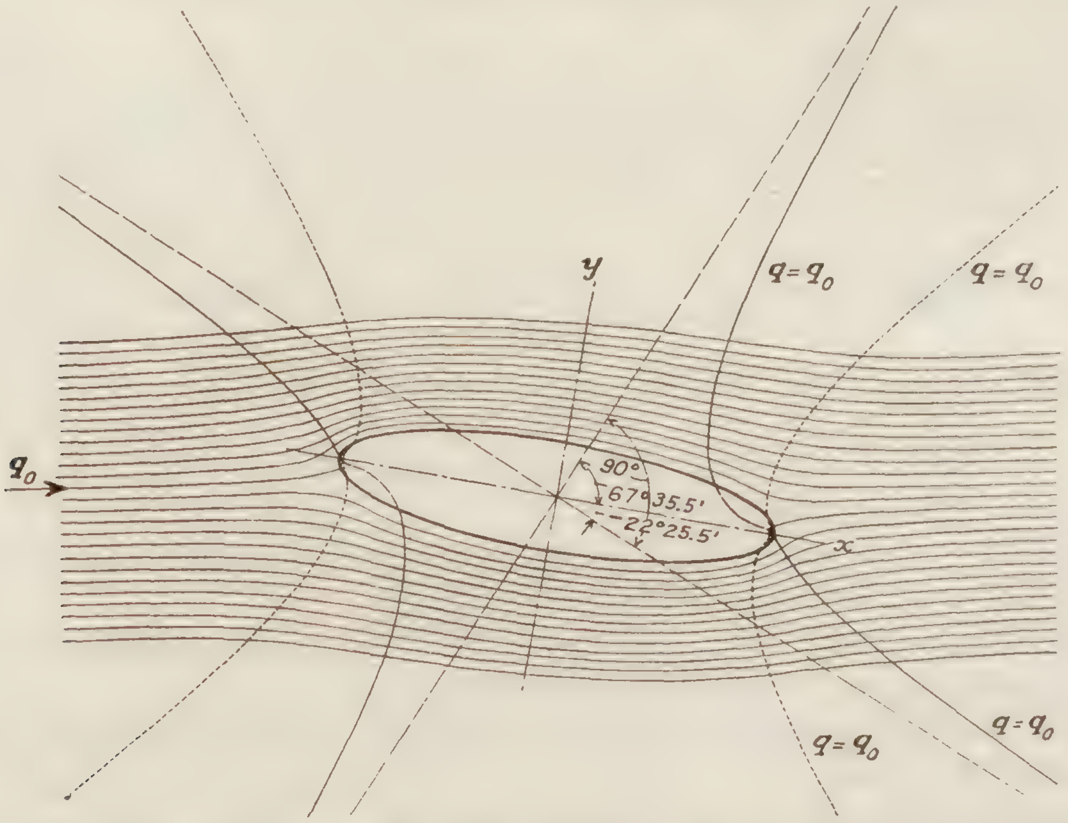


FIG. 23.—Lines of steady flow, lines of constant speed and pressure, for infinite frictionless liquid streaming across endless elliptic cylinder. Dotted curve refers to stream parallel to x; full-line curve $q=q_o$ refers to stream inclined 10° to x

The two values of $\tan \beta$ in (42) are

$$\tan \beta_1 = \frac{K}{B}(A+\sqrt{BC+A^2}), \qquad \tan \beta_2 = \frac{K}{B}(A-\sqrt{BC+A^2}), \tag{43}$$

from which are readily derived

$$\tan (\beta_1-\beta_2) = \frac{2K\sqrt{BC+A^2}}{B-K^2C}, \qquad \tan (\beta_1+\beta_2) = \frac{2KA}{B+K^2}. \tag{44}$$

(43) give the x-ward inclinations β_1, β_2, of the asymptotes of the curves $q=q_o$. As can be proved, the interasymptote angle $\beta_1-\beta_2$ remains constant as $K(=V/U)$ varies and the asymptotes rotate through $\frac{1}{2}(\beta_1+\beta_2)$ about the c axis.

Thus, with an elliptic cylinder, giving A, B, C their values at ∞ makes

$$\tan (\beta_1-\beta_2) = \infty, \qquad \tan (\beta_1+\beta_2) = \frac{K(a+b)}{b-aK^2}; \tag{45}$$

hence the asymptotes continue rectangular, as in Figure 23, while with varying angle of attack they rotate through $\frac{1}{2}(\beta_1+\beta_2)$. Or more generally one may show that $\frac{d}{da}(\beta_1-\beta_2)=0 \therefore \beta_1-\beta_2=$ const.

A similar treatment applies to the other figures of Table III. For all the cylinders the interasymptote angle is 90°; for the spheroids it is $2\tan^{-1}\sqrt{2}=109°-28'$ in the ab plane. Figure 17 is an example. If the flow past the spheroids is parallel to the bc plane the interasymptote angle for the curves $q=q_o$ in that plane is obviously unaffected by stream direction. It is 90° for infinitely elongated spheroids; $109°-28'$ for all others. Excluded from the generalizations of this paragraph are the infinitely thin figures, such as disks and rectangles edgewise to the stream, that cause no disturbance of the flow. Passing to three dimensions, we note that the asymptotic lines form asymptotic cones having their vertex at the origin.

SUMMARY

For an infinite inviscid liquid streaming uniformly, in any direction, past an ellipsoid or simple quadric:

1. The velocity potential at any confocal surface point equals the greatest tangential speed along that surface times the distance from the point to the surface's zero-potential plane.
2. The tangential flow speed at said surface point equals the greatest tangential speed times the sine of the obliquity, or inclination of the local surface element to the equipotential plane.
3. The normal speed at the point equals the greatest normal speed times the cosine of the obliquity.
4. The locus of $q=q_o$ is a cup-shaped surface asymptoting a double cone with vertex at the center.
5. The vertex angle of this cone is invariant with stream direction; for cylinders it is 90°, for spheroids it is $2\tan^{-1}\sqrt{2}=109°-28'$.
6. The velocity and pressure distribution are closely the same as for air of the same density, except in or near the region of disturbed flow.
7. The zonal drag is upstream on the fore half; downstream on the rear half; zero on the whole. These zones may be bounded by the isobars, ϵ const.

For the same stream, but with kinematic viscosity ν, if the dynamic scale is $R=q_o d/\nu$, d being the model's diameter:

8. The drag coefficient of a sphere is $24/R$ for $R<.2$; $28R^{-.85}+.48$ for $0.2<R<200{,}000$; and 0.5 for $10^4<R<10^5$.
9. The drag coefficient of an endless round cylinder fixed across stream is $8\pi/R(2.002-\log_e R)$ for $R<.5$; approximately $9.4\ R^{-.8}+1.2$ for $0.5<R<200{,}000$; 1.2 for $10^4<R<200{,}000$.
10. For $15{,}000<R<200{,}000$ the drag coefficient of a round cylinder is 2.4 times that for a sphere.

TABLE III

Flow functions for simple quadrics in stream V along y positive

(For all shapes $\phi=-(1+m_b)\,Vy$, $q_t=(1+m_b)\,V\sin\epsilon$* $q_n=-(1-n_b)\,V\cos\epsilon$)

Shape	m_b	n_b
Sphere	$\frac{a^3}{2a'^3}$	$\frac{a^3}{a'^3}$
Circular cylinder	$\frac{a^2}{a'^2}$	$\frac{a^2}{a'^2}$
Elliptic cylinder	$\frac{a}{b'}\,\frac{a+b}{a'+b'}$	$\frac{a}{a'}\,\frac{a+b}{a'+b'}$
Prolate spheroid $e=\frac{1}{a}\sqrt{a^2-b^2}$	$-\dfrac{\log_e\frac{1+e'}{1-e'}-\frac{2e'}{1-e'^2}}{\log_e\frac{1+e}{1-e}-2e\,\frac{1-2e^2}{1-e^2}}$	$\dfrac{\log_e\frac{1+e'}{1-e'}-2e'\,\frac{1-2e'^2}{1-e'^2}}{\log_e\frac{1+e}{1-e}-2e\,\frac{1-2e^2}{1-e^2}}$
Oblate spheroid $e=\frac{1}{b}\sqrt{b^2-a^2}$	$-\dfrac{e'\sqrt{1-e'^2}-\sin^{-1}e'}{e\,\frac{1+e^2}{\sqrt{1-e^2}}-\sin^{-1}e}$	$\dfrac{e'\,\frac{1+e'^2}{\sqrt{1-e'^2}}-\sin^{-1}e'}{e\,\frac{1+e^2}{\sqrt{1-e^2}}-\sin^{-1}e}$

* ϵ is the angle between b' and any normal to the confocal surface.

TABLE IV

Inertia factors k_b for quadric surfaces in steady translation along axis b in Figure 20

Elongation E	Ellip. cyl $E=a/b$ $k_b=\frac{a}{b}$	Prol. spher. $E=a/b$ $k_b=-\dfrac{\log_e\frac{1+e}{1-e}-\frac{2e}{1-e^2}}{\log_e\frac{1+e}{1-e}-2e\,\frac{1-2e^2}{1-e^2}}$	Obl. spher. $E=b/a$ $k_b=-\dfrac{e-E\sin^{-1}e}{eE^2(e^2+1)-E\sin^{-1}e}$
1.00	1.00	0.500	0.500
1.50	1.50	.621	.384
2.00	2.00	.702	.310
2.50	2.50	.763	.260
3.00	3.00	.803	.223
4.00	4.00	.860	.174
5.00	5.00	.895	.140
6.00	6.00	.918	.121
7.00	7.00	.933	.105
8.00	8.00	.945	.092
9.00	9.00	.954	.084
10.00	10.00	.960	.075
∞	∞	1.000	0

The numerical values in column 3 are given in Lamb's paper already cited; those in column 4 are given substantially by Doctor Bateman, Report No. 163 National Advisory Committee for Aeronautics, 1923.

REPORT No. 254

DISTRIBUTION OF PRESSURE OVER MODEL OF THE UPPER WING AND AILERON OF A FOKKER D-VII AIRPLANE

By A. J. FAIRBANKS
Langley Memorial Aeronautical Laboratory

REPORT No. 254

DISTRIBUTION OF PRESSURE OVER MODEL OF THE UPPER WING AND AILERON OF A FOKKER D-VII AIRPLANE

By A. J. Fairbanks

SUMMARY

This report describes tests made in the atmospheric wind tunnel of the National Advisory Committee for Aeronautics for the purpose of determining the distribution of pressure over a model of the tapered portion of the upper wing and the aileron of a Fokker D-VII airplane. Normal pressures were measured simultaneously at 74 points distributed over the wing and aileron. Tests were made throughout the useful range of angles of attack with aileron setting ranging from −20° to +20°. The results are presented graphically.

It was found that the pressure distribution along the chord is in general similar to that of thick tapered airfoils previously tested. The maximum resultant pressure recorded was five times the dynamic pressure. The distribution of the air load along the span may be assumed to be uniform for design purposes.

Aileron displacements affect the pressures forward to the leading edge of the wing and may increase the air load on the outer portion of the wing by a considerable amount. With the wing at large angles of attack, the overhanging portion of the aileron creates usually a burbled flow and therefore a large drag. The balance reduces the control stick forces at small angles of attack for all aileron displacements. At large angles of attack it does this for small displacements only. With the airplane at its maximum speed, an angle of attack of 18°, and a down aileron displacement of 20°, the bending moment tending to break off the overhanging portion of the aileron will be greater than that caused by a uniform static load of 35 pounds per square foot.

INTRODUCTION

This is a report on the continuation of the tests on thick tapered airfoils which were requested by the United States Army Air Service. The object of the investigation is to determine the distribution of pressure over representative wings of this type. A previous report (Reference 1) covers tests on three airfoils which were tapered both in thickness and in plan form

In these tests a model of the tapered portion of the left upper wing and the aileron of a Fokker D-VII airplane was used. The wing, which is rectangular in plan form, has an aspect ratio of 5.2 and is equipped with ailerons of the horn balance type. The center section is 25.3 per cent of the span and has a constant thickness. The outer portions of the wing are tapered linearly to a tip thickness of 62 per cent of that at the center. Because the model represents only the tapered portion of the wing and the effect of the dividing plane is to reflect the action of a similar opposite model, the result is actually a model of a wing with an aspect ratio of approximately four. It is not thought, however, that the omission of the central portion of the wing will greatly affect the results. The model aileron was made movable in order that the effect of such a balanced control might be investigated.

METHOD AND APPARATUS

In these tests the method used was to record the heights of columns of alcohol in multiple photomanometers which were connected by air-tight tubes to orifices in the model's surface. The tests were made in the 5-foot atmospheric wind tunnel at the Langley Memorial Aeronautical Laboratory. The tests covered a range of angles of attack of from −6° to +24°. The aileron angles investigated were 0°, and ±10°, and ±20°.

The wing was made by hand of laminated mahogany in which small brass tubes were inlaid. Figure 1 is a drawing of the model on which is shown the location of the pressure orifices. The aileron was constructed of brass. Two blanks were milled to contours and grooved; pressure tubes were inlaid, and then sweated together. The surfaces were finished by hand. The tubes were led through a channel in the wooden part of the wing. This channel was left open during assembly and was later covered by a steel plate which formed part of the model's surface. Figure 2 is an illustration of this assembly with the cover removed. In all 74 tubes were used.

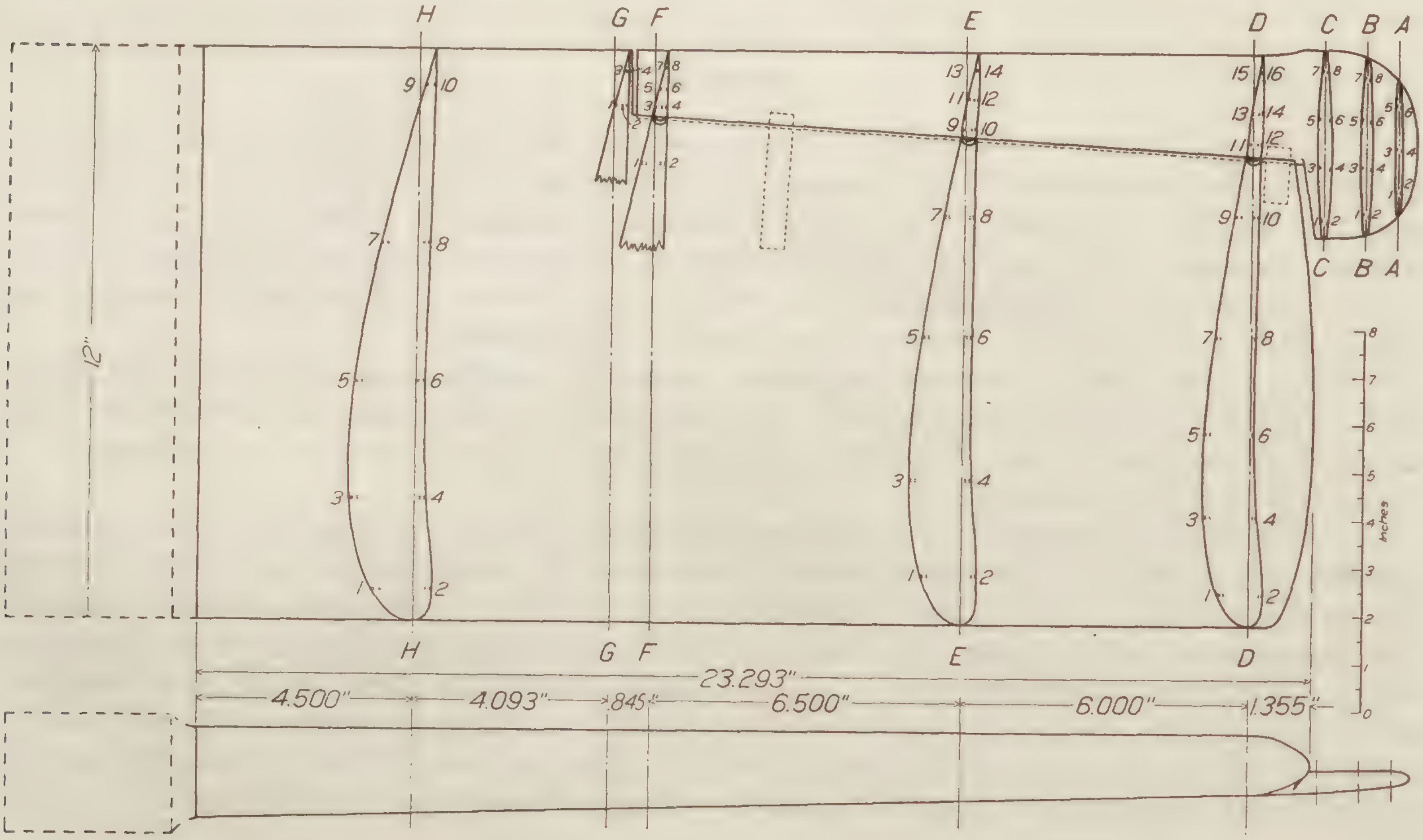


FIG. 1.—Pressure distribution model of the upper wing and aileron of Fokker D-VII Airplane

The model was mounted vertically at its root and could be rotated about a vertical axis. It passed through a horizontal plane fixed in the wind tunnel at the level of the root section. Figure 3 is a general view of this installation. The general details of construction and installation are the same as those of the former tests. (Reference 1.)

The angle of attack of the wing was set with the aid of a vernier scale and the aileron angle with the aid of a small telescopic sight. To take a record the wing and the aileron were brought to the required angles. When the velocity had become uniform at the desired value, the manometers were loaded with photostat paper, and simultaneous records were then taken. A sample of the photostat records is reproduced in Figure 4.

The air speed was approximately 66 feet per second. This gave maximum pressures that did not exceed the recording range of the manometers. Velocity surveys were made along a vertical diameter of the tunnel one chord length ahead of the wing with the wing at 0° and 18° angle of attack. The mean dynamic pressure was used in computations. Because no difficulty was experienced in fairing the pressure diagrams to the full dynamic pressure at the leading edge of the lower surface, it is not felt that the interference of the wing on the velocity measurement caused any perceptible error.

REDUCTION OF DATA

The photostat paper recorded the heights of the columns of alcohol, which represent the differences between the pressures at the orifices and the pressure at the wall of the tunnel opposite the leading edge of the wing, which is indistinguishable from the static pressure in the air stream opposite the leading edge of the model and at some distance from it. These pressure heads were divided by the mean dynamic pressure head and the resulting ratios were plotted along the test section chords.

In these pressure charts the resultant pressure at any point along the chord is represented by the vertical distance between the pressure curves for the upper and lower surfaces. These resultant pressures were plotted along the chords of the test sections. The curves of constant resultant pressure were then determined from the pressure charts and mapped on a plan view of the model.

When the inclosed area of the pressure charts are divided by a characteristic length, i. e., the wing chord, a nondimensional coefficient is obtained, which is proportional to the air load per unit span at the test section. These values are plotted against the span.

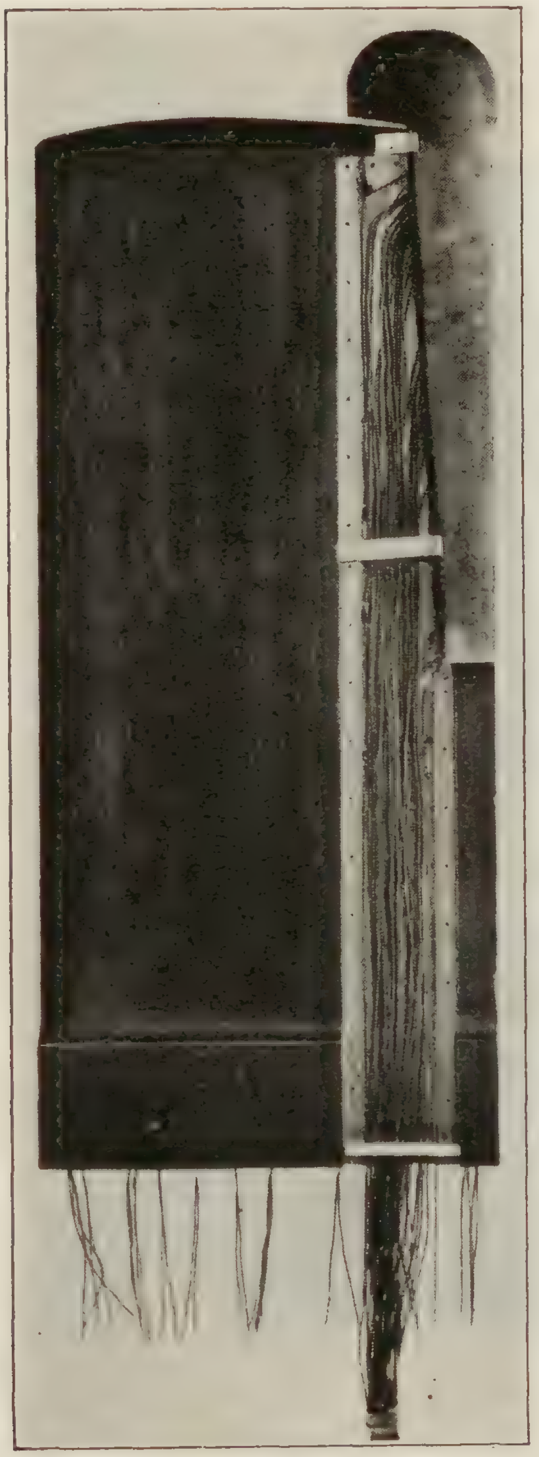


FIG. 2.—Model with plate removed, showing attachment of aileron

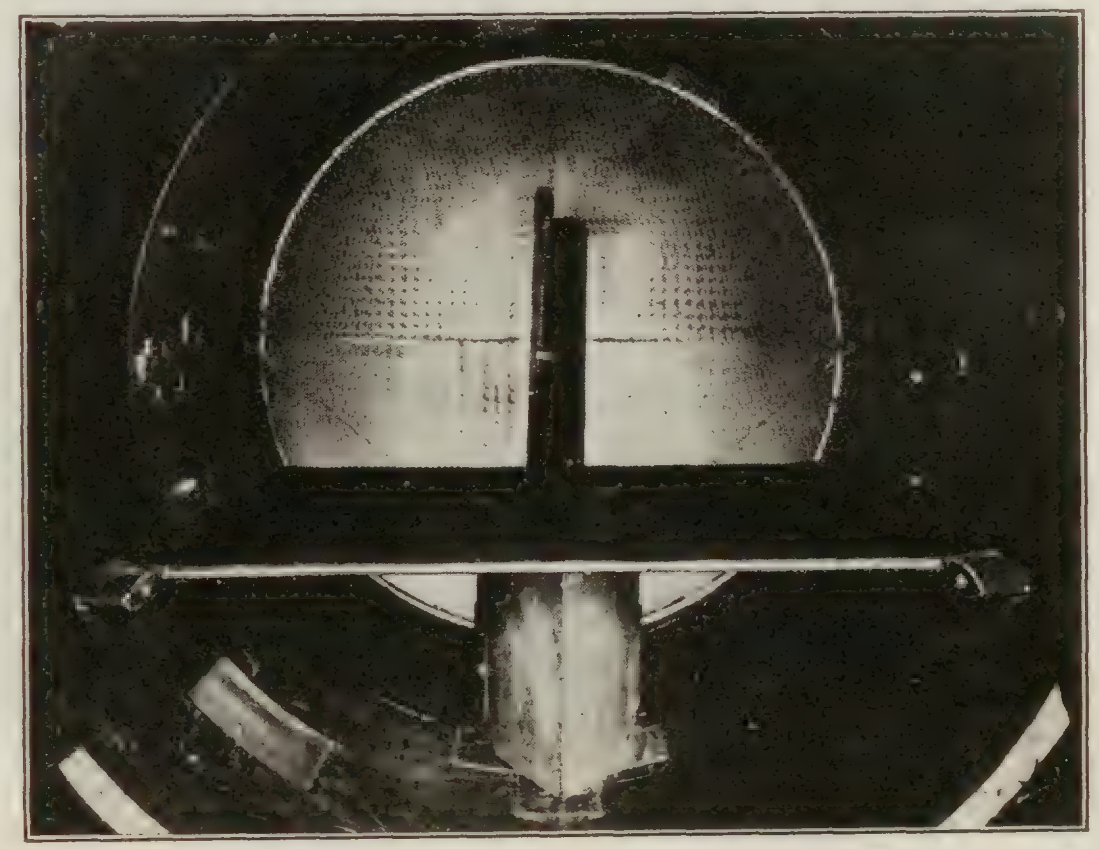


FIG. 3.—View of installation in the wind tunnel

The aileron hinge moments per unit span were obtained from the individual pressure charts with the aid of a mechanical moment integrator. The total hinge moment was obtained by integrating the hinge moments per unit span along the span. Omitting the moment of the overhanging portion, we obtain the approximate hinge moment of an unbalanced aileron. A plot of the hinge moments per unit span against the aileron span showed that the moment approached zero in every case at the point at which the tip of an unbalanced aileron would have been. Thus it is thought that this approximation is permissible. By dividing the moment of two interconnected balanced ailerons by the moment of two interconnected unbalanced ailerons, ratios were obtained which express approximately the effectiveness of the balance in reducing the required control stick force.

The bending moment tending to break off the overhanging portion of the aileron was determined similarly from plots of loading along the span of the aileron.

PRESENTATION OF RESULTS

The results are presented by Figures 5 to 26. Figures 5 and 6 are charts of pressures on the upper and lower surfaces at the test sections. Figure 7 is a plot of the air loading per unit span against span, showing the effect of angle of attack. The effect of aileron displacement on the resultant pressures along the chord is pictured in Figure 8. Figures 9 and 10 are plots similar to Figure 7 but illustrate the effect of aileron displacement. Figures 11 to 24 are contour maps of resultant pressures. In Figure 25 the ratio of the hinge moment of two balanced ailerons to the hinge moment of two unbalanced ailerons is plotted against the angle of aileron displacement. In Figure 26 the centers of pressure are plotted against both angle of attack and angle of aileron displacement.

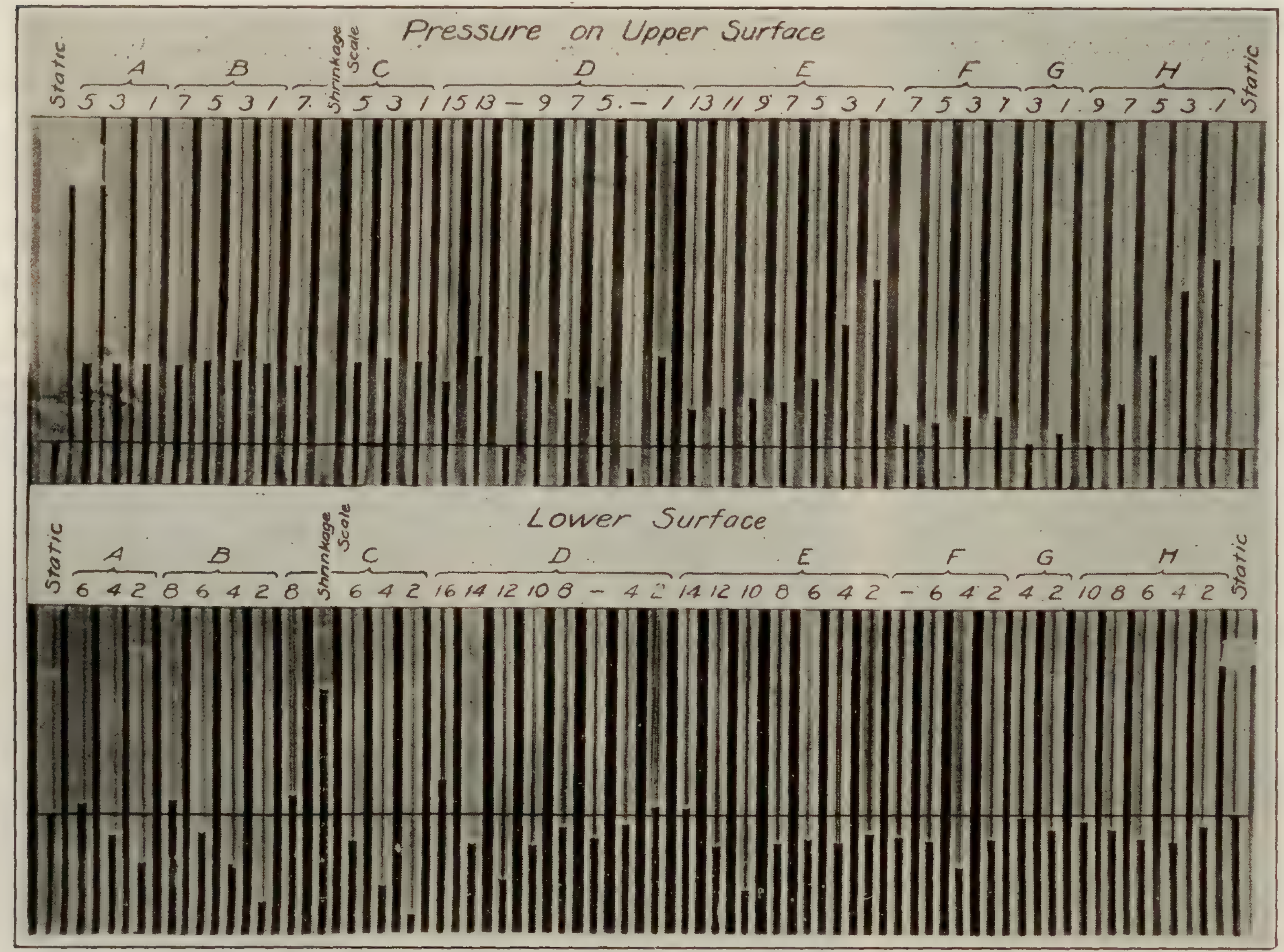


FIG. 4.—A pair of photostat records

DISCUSSION OF RESULTS

The pressure charts are similar to those for the three previously tested airfoils. (Reference 1.)

The maximum resultant pressure is five times the dynamic pressure and is greater than that recorded for any airfoil previously tested at this laboratory. The results of the tests on this airfoil are in agreement with the conclusion in Reference 1 that the maximum resultant pressure depends upon both the rate of increase of the thickness of the forward part of the airfoil and the shape of its mean camber line.

The distribution of the air load along the span, as shown by Figure 7, demonstrates that tapering an airfoil in thickness only is not necessarily an effective method for reducing the loading toward the tip. This is in agreement with the results of former tests of models which were tapered even more in thickness. (Reference 2.) The span-load curves of Reference 2 illustrate the greater effectiveness of tapering the plan form for obtaining small pressures near the tip.

The distribution of the air load along the span of the Fokker D–VII wing, as shown in Figure 7, may be assumed to be uniform for design purposes.

The effect of aileron displacement on the loading along the chord is illustrated by Figure 8. The pressures are modified forward to the leading edge, but the greatest change is over the aileron itself. A region of increased loading extends along the aileron hinge. (See figs. 11 to 24.) Similar irregularities have appeared in the results of previous tests. (Reference 3.) In the individual pressure charts, Figures 5 and 6, it may be seen that with a neutral or depressed aileron the rapid change of pressure is confined to the lower surface. With a raised aileron both surfaces experience this sudden change.

The effect of aileron displacement on the air loading along the span is shown in Figures 9 and 10. The intensity of loading over the outer portion of the wing is increased by depressing the aileron. With the wing at 18° angle of attack, an aileron depression of 20° will cause an increase in the air load on the tapered portion of the wing of 11.5 per cent. The bending moment at the inner end of the tapered section will be increased 15 per cent. In the design of wing structure, special air loads caused by aileron displacement should not be neglected.

The overhanging portion of the aileron is similar to an airfoil of poor aspect ratio; with the wing at a positive lift, it is always in a region of upflow. The distribution of the pressure along the chord is shown in Figures 5 and 6. The uniformity of pressure over the upper surface (see fig. 6) indicates that the overhanging area has given rise to burble. In this condition its drag is relatively large. The distribution of the resultant pressures over this part of the aileron is shown in Figures 11 to 24.

The most heavily loaded part of the aileron is that beyond the wing tip. As this is a cantilever structure and the thickness of the section at which it is supported is comparatively small, the strength of this section needs particular attention. The bending moment caused by the air forces at 18° angle of attack and 20° down aileron was compared with the bending moment caused by the application of a uniform static load of 35 pounds per square foot. The bending moment imposed by the sand load is smaller than the bending moment caused by the air load, if this airplane is brought to the above-mentioned attitude at its maximum speed.

The comparison of hinge moments shown in Figure 25 illustrates, in general, the effectiveness of the aileron balance. Inaccuracies are introduced by the use of a model of less than half span with a reflecting plane and by the assumption that the forces on the inner portion of the aileron are the same as those on an unbalanced aileron. However, we do not believe that these inaccuracies are of such magnitude as to obscure the principal points of interest. Considering now pairs of interconnected ailerons, the balanced pair requires smaller control forces than the unbalanced pair for all displacements at small angles of attack. At large angles of attack, however, this holds only for small displacements.

This may be explained as follows: At large angles of attack, the forces on the overhanging portion of the aileron always produce a moment tending to lower the trailing edge. The forces on the inner portion of the aileron always produce a moment tending to return the aileron to neutral. Thus, if the aileron is displaced upward, both moments are in the same direction and the resulting moment is greater than the corresponding moment for an unbalanced aileron. On the other hand, if the aileron is displaced downward the two moments will be in opposite directions and the result will be a smaller moment than would be found on the corresponding unbalanced aileron. Whether the control force for interconnected ailerons will be increased or decreased by the balance will depend upon which of these two effects is greater. In Figure 25 it can be seen that at 18° angle of attack either of these two effects can exist according to the angle of aileron displacement.

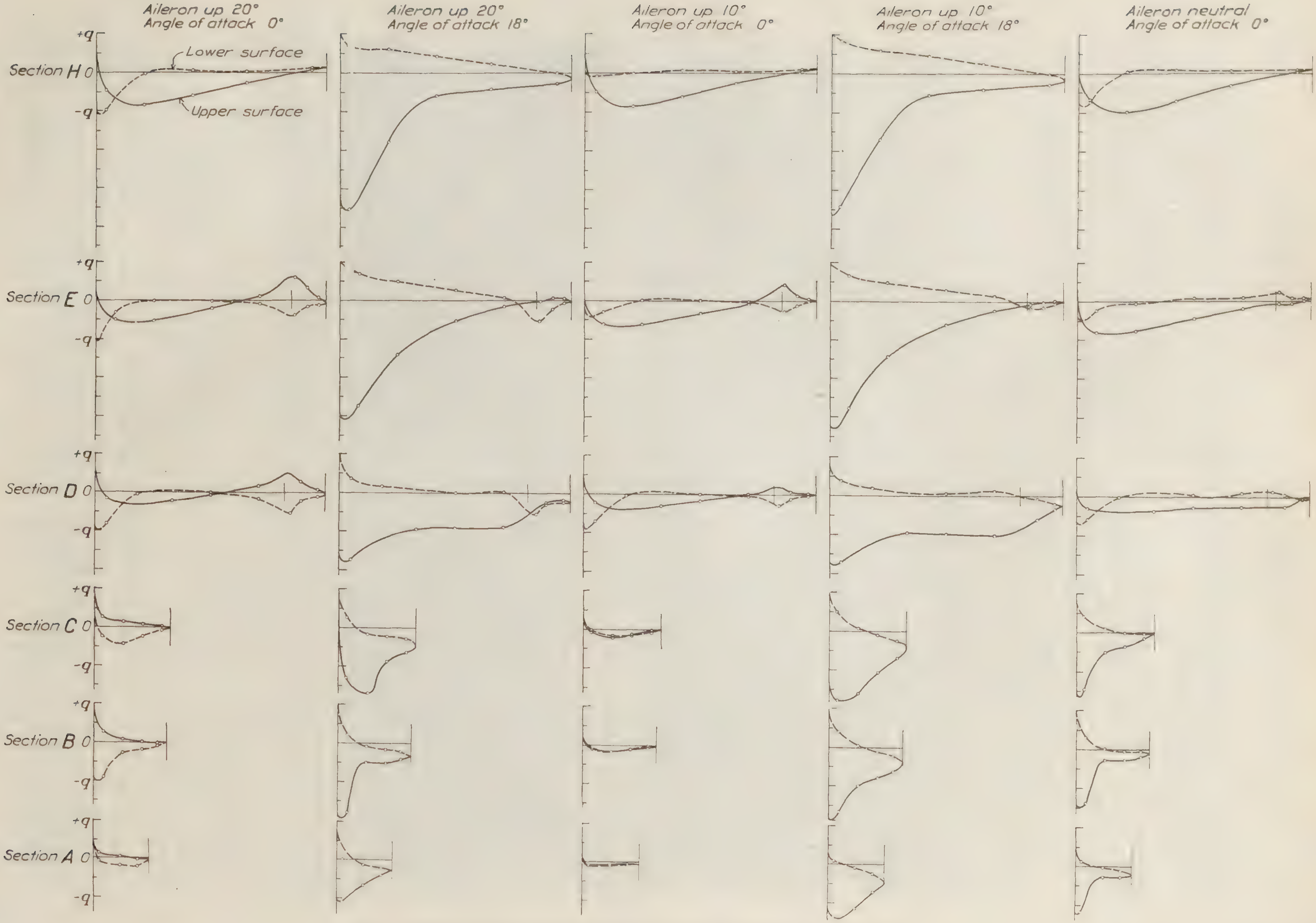


FIG. 5.—Charts of pressure on upper and lower surfaces at test sections, A, B, C, D, E, and H

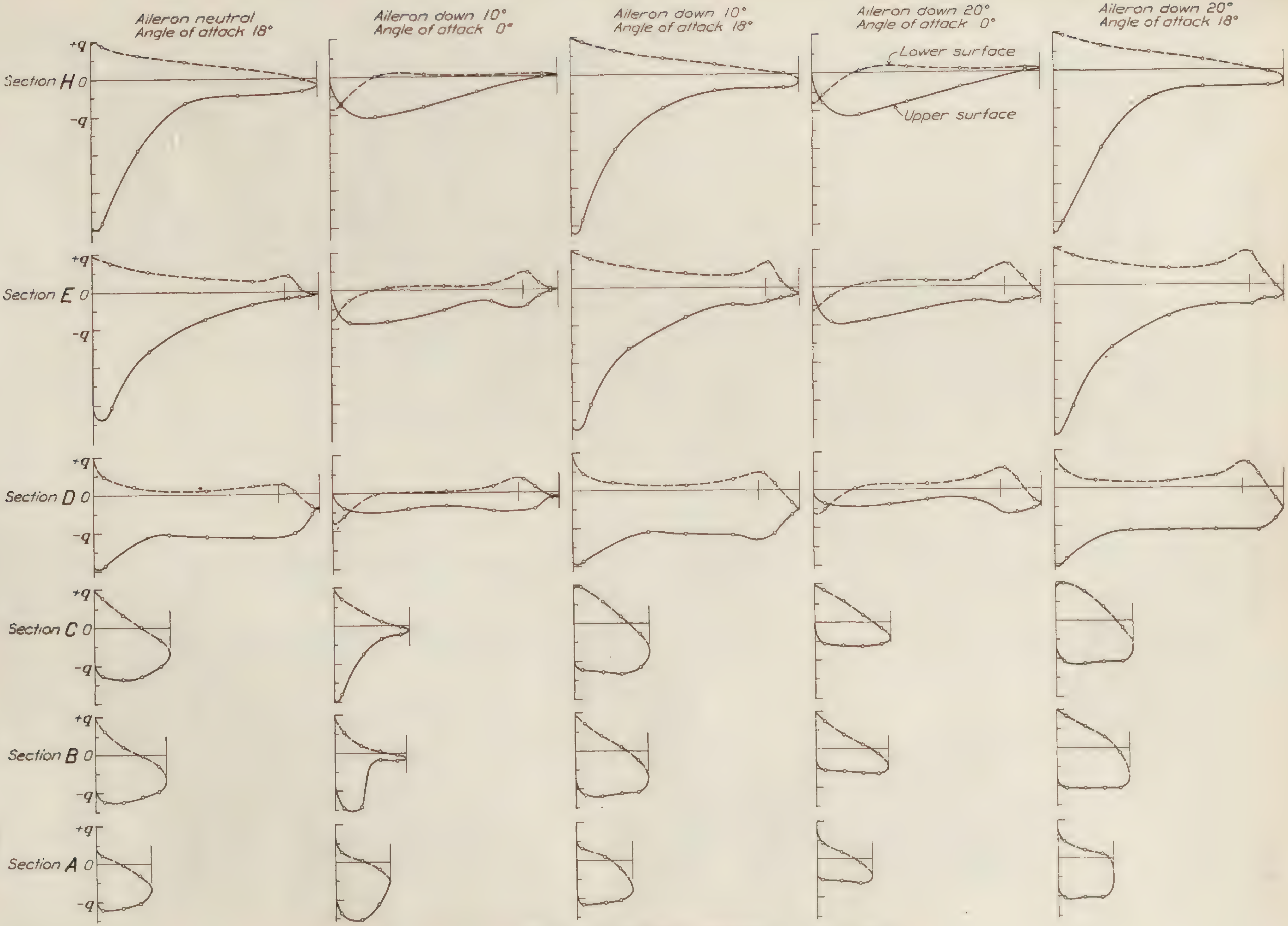


FIG. 6.—Charts of pressure on upper and lower surfaces at test sections, A, B, C, D, E, and H

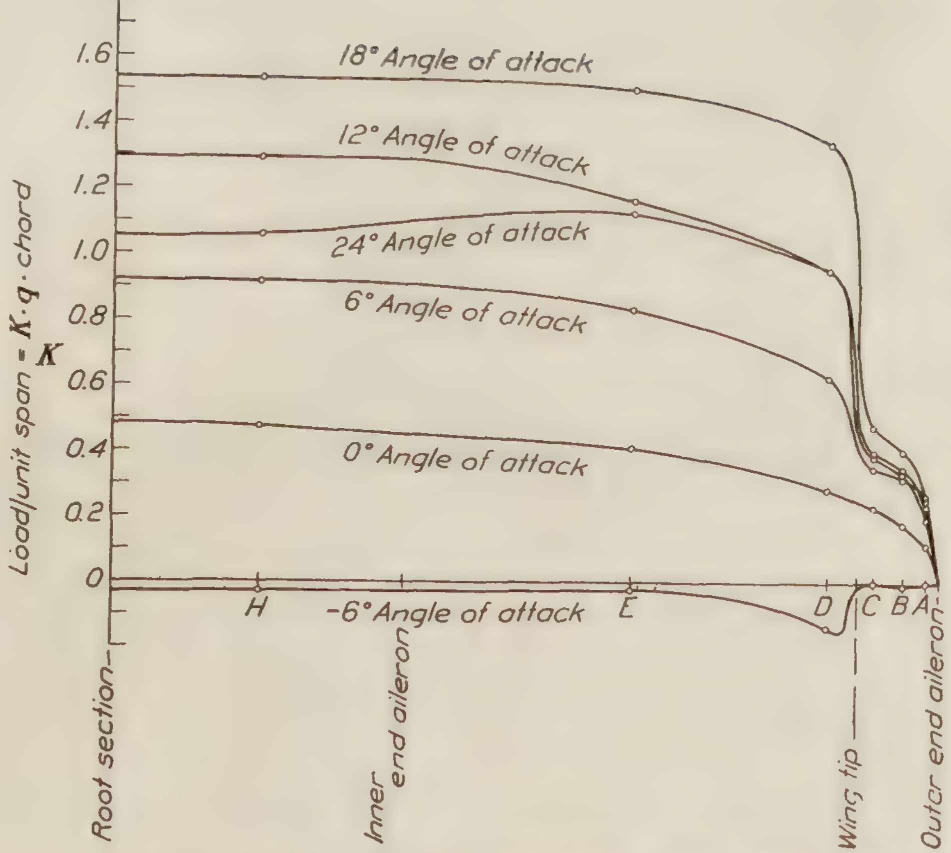


FIG. 7.—Air load distribution along span. Aileron neutral

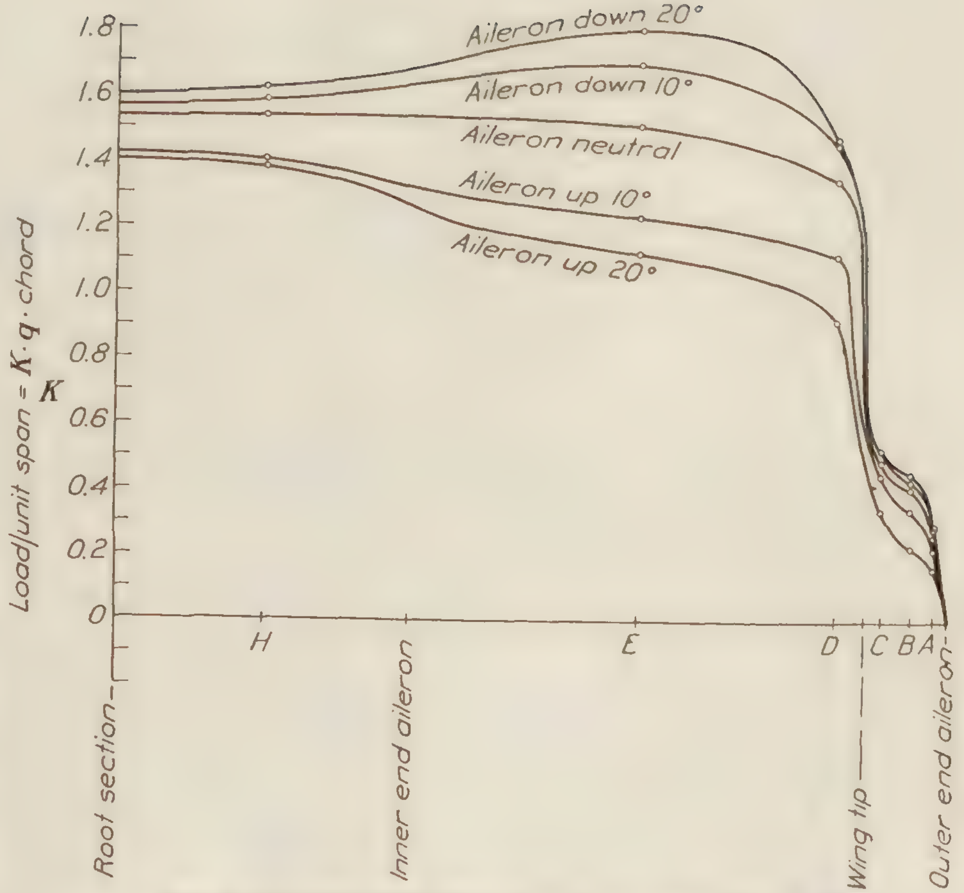
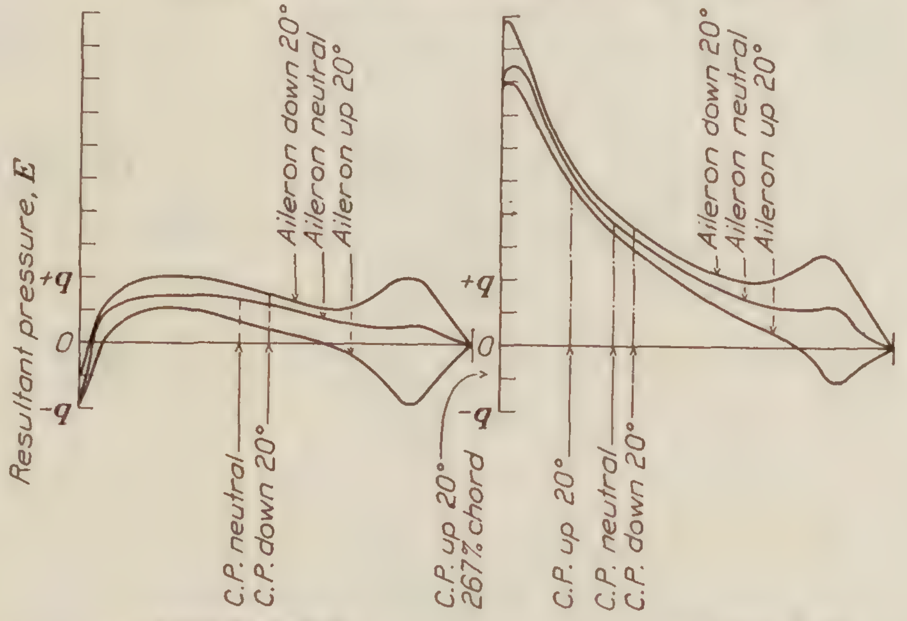


FIG. 10.—Air load distribution along span. Angle of attack 18°



Angle of attack 0°

Angle of attack 18°

FIG. 8.—Effect of aileron displacement on resultant pressure along chord of section E

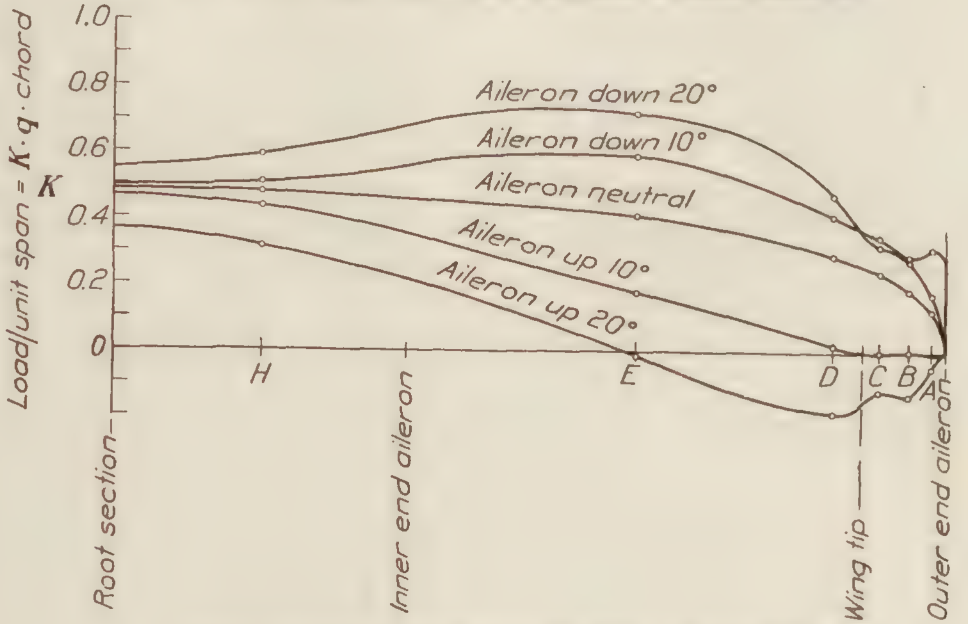


FIG. 9.—Air load distribution along span Angle of attack 0°

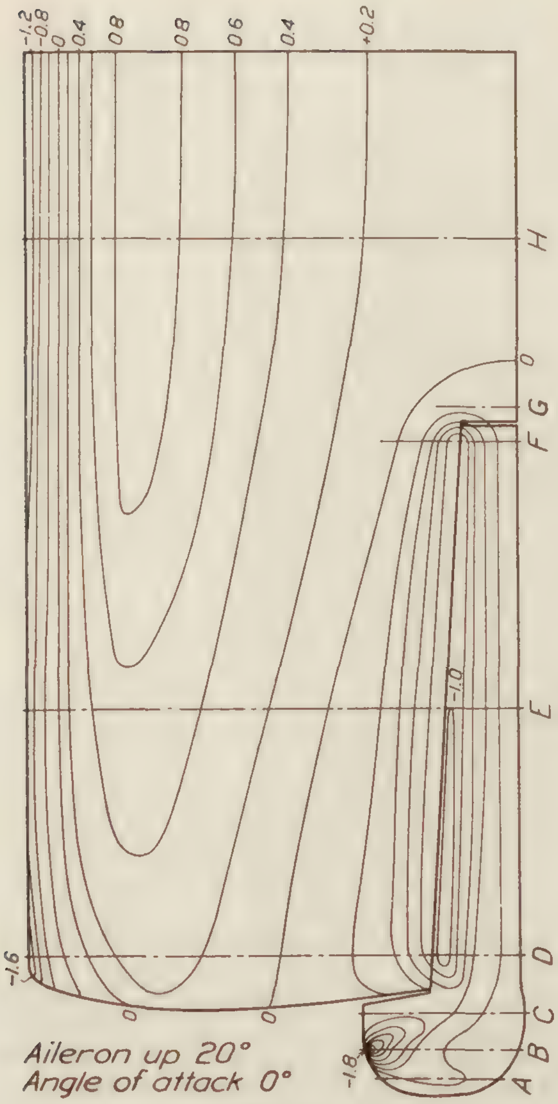


FIG. 11

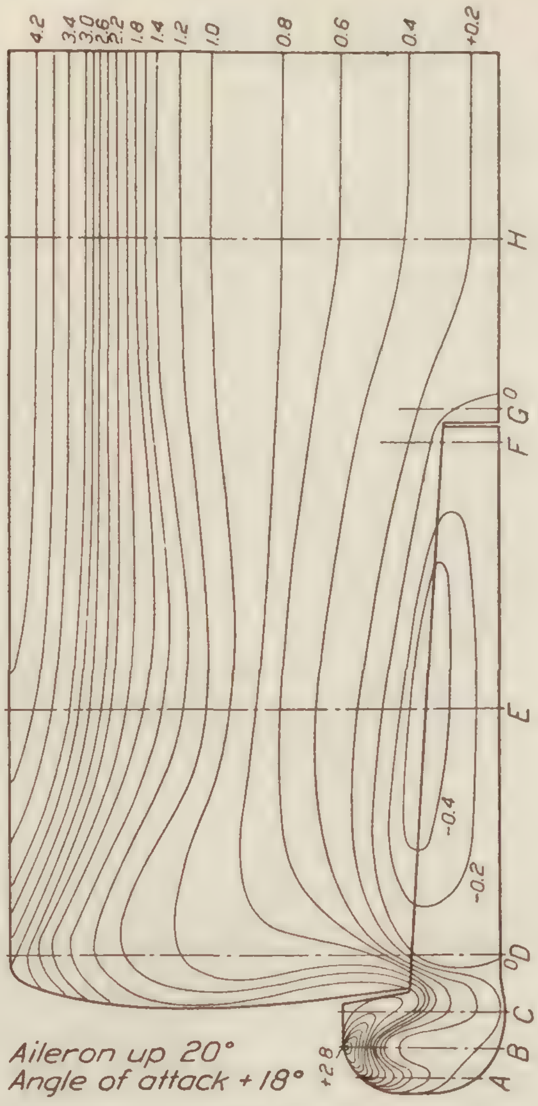


FIG. 12

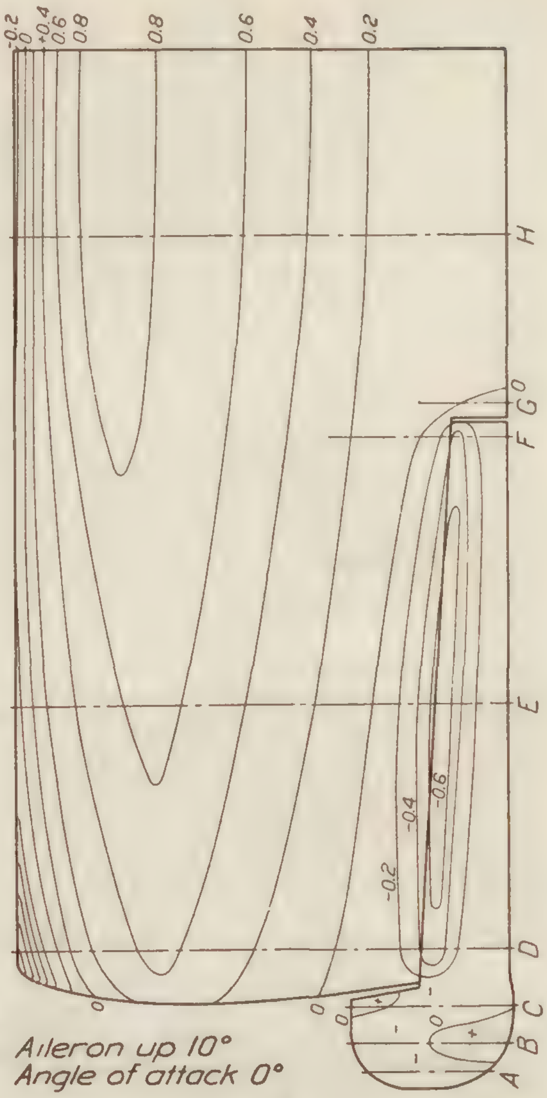


FIG. 13

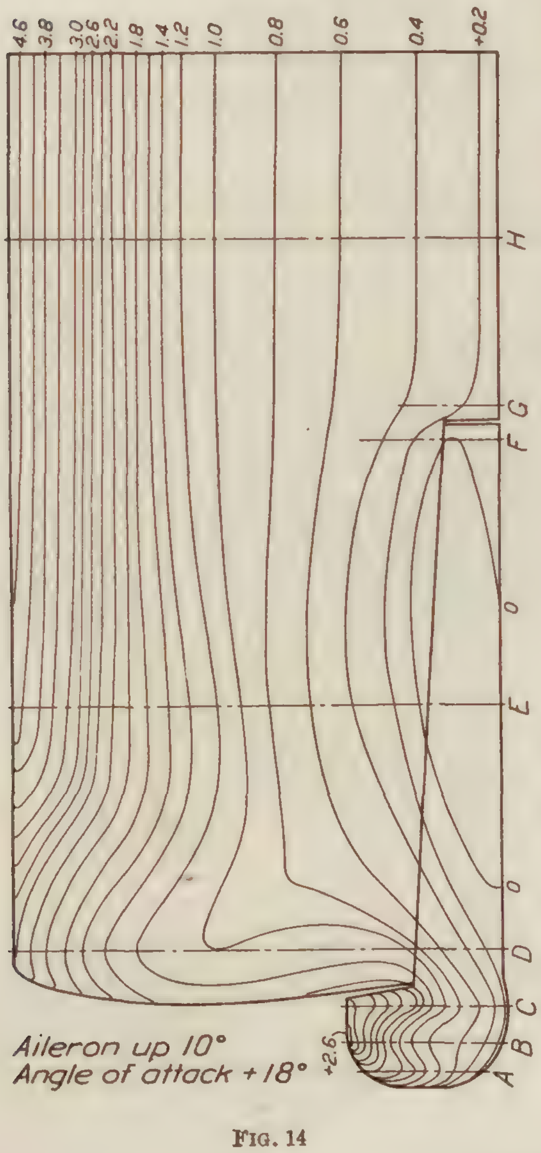


FIG. 14

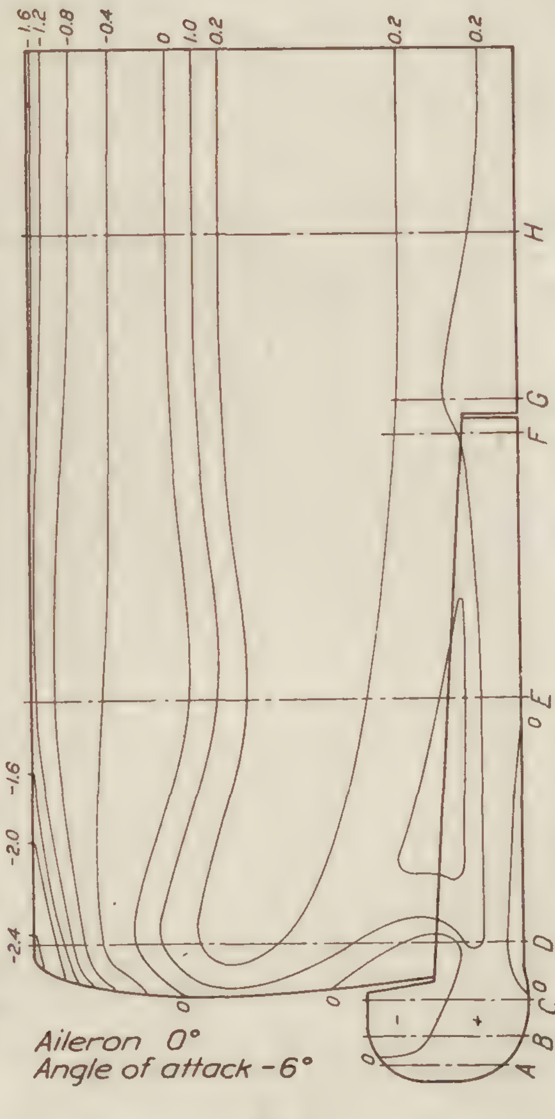


FIG. 15

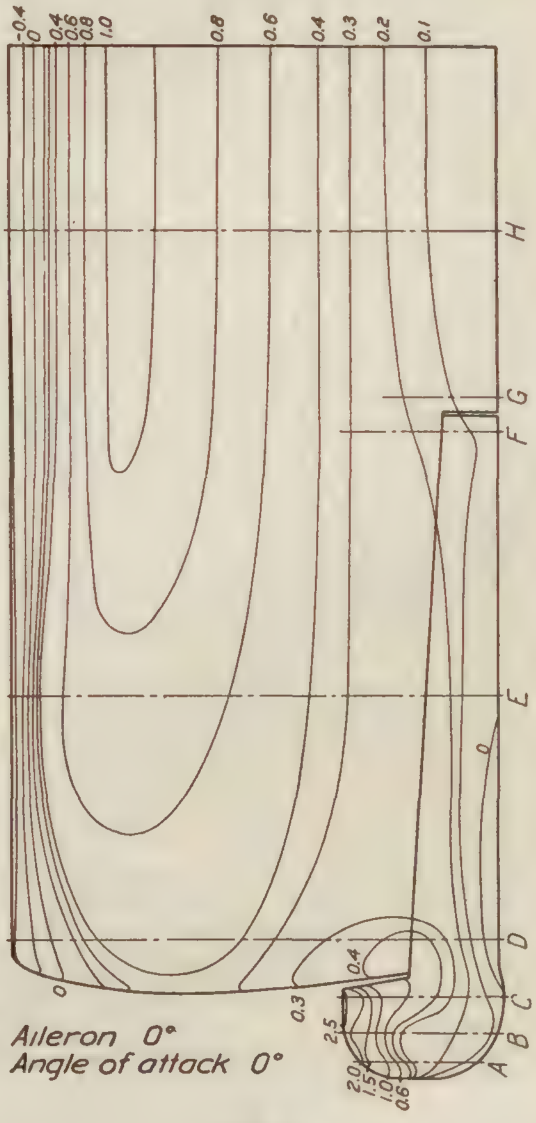


FIG. 16

Contour charts of resultant pressures in terms of *q*

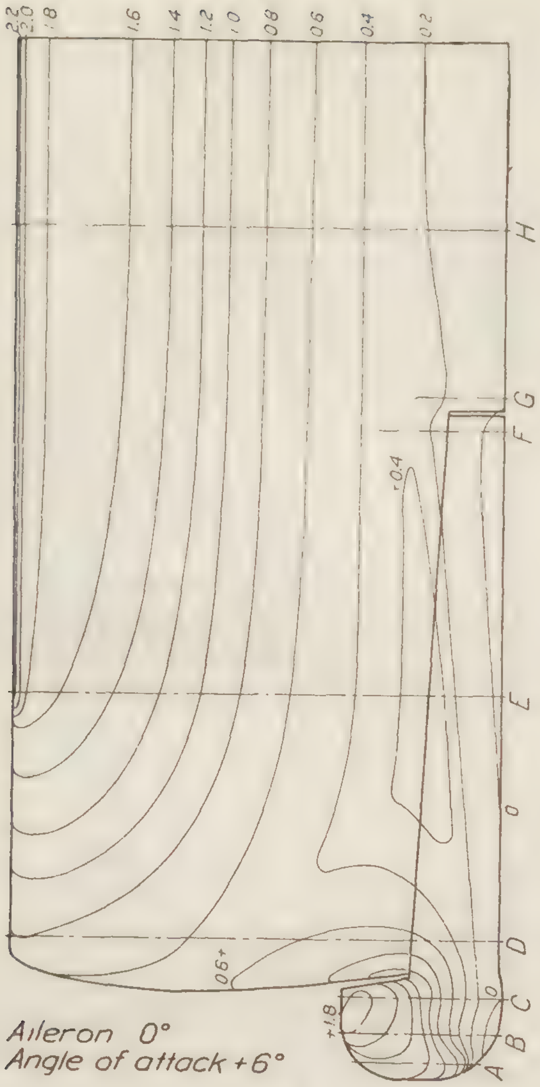


FIG. 17

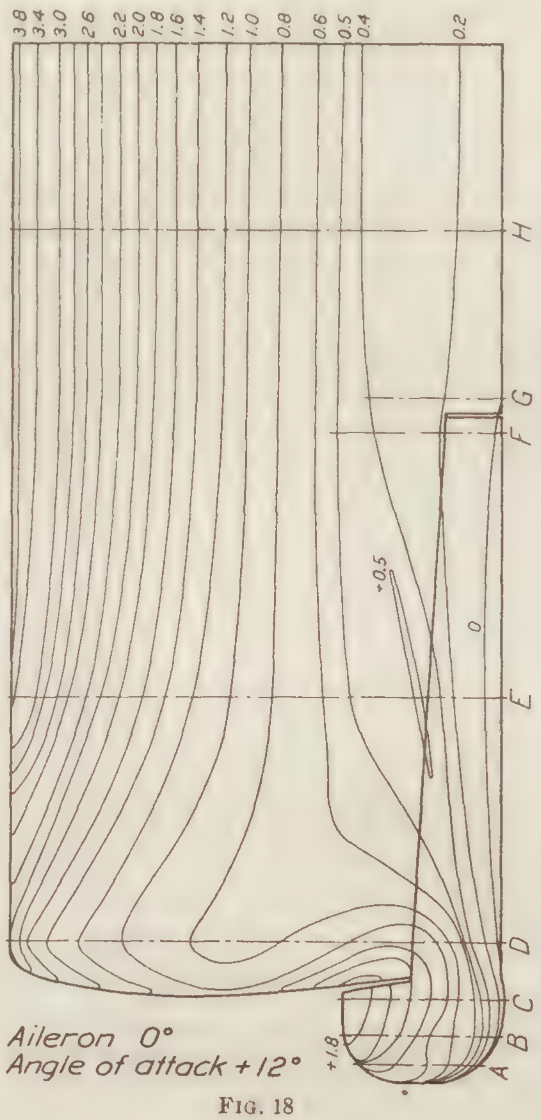


FIG. 18

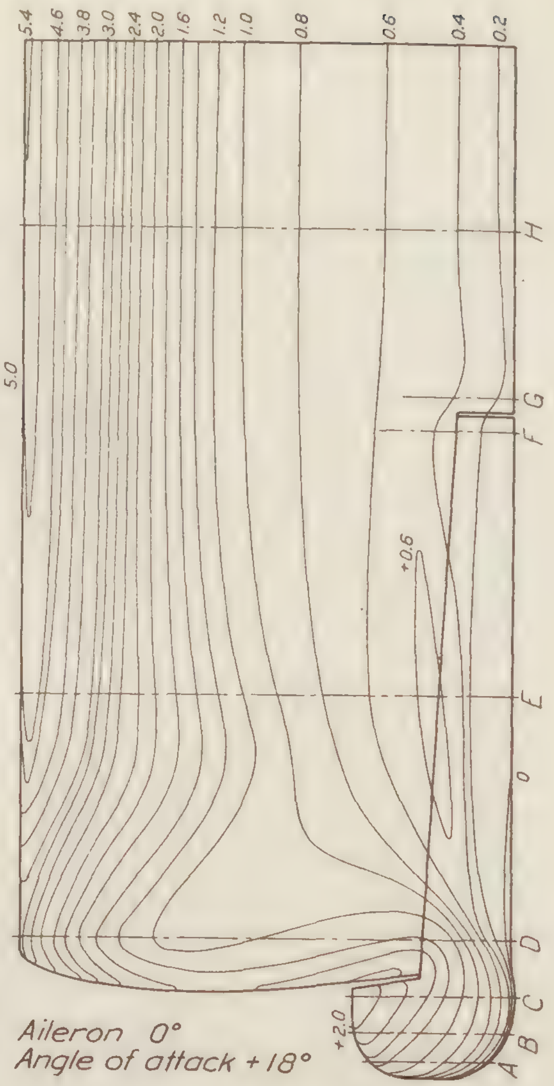


FIG. 19

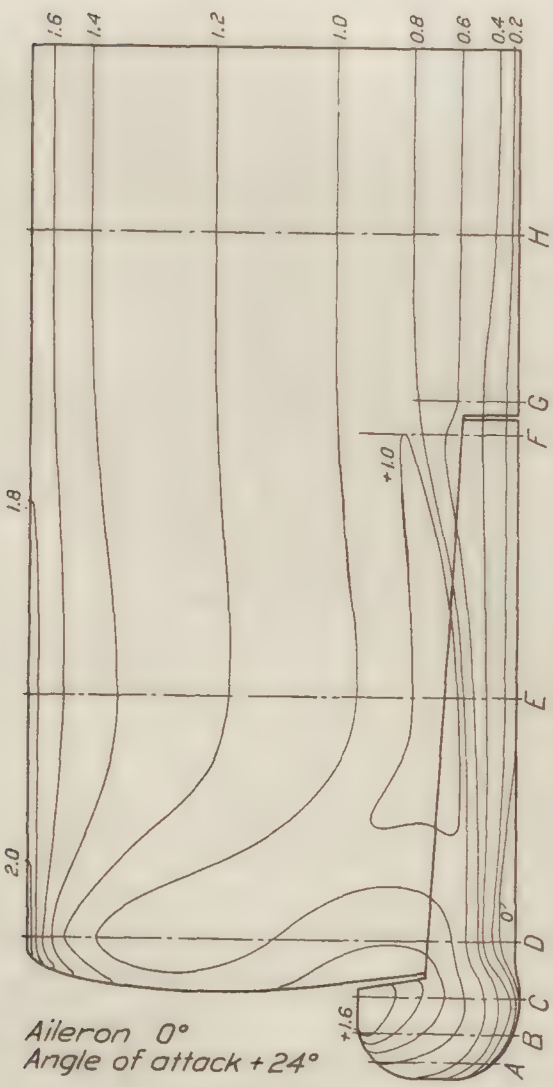


FIG. 20

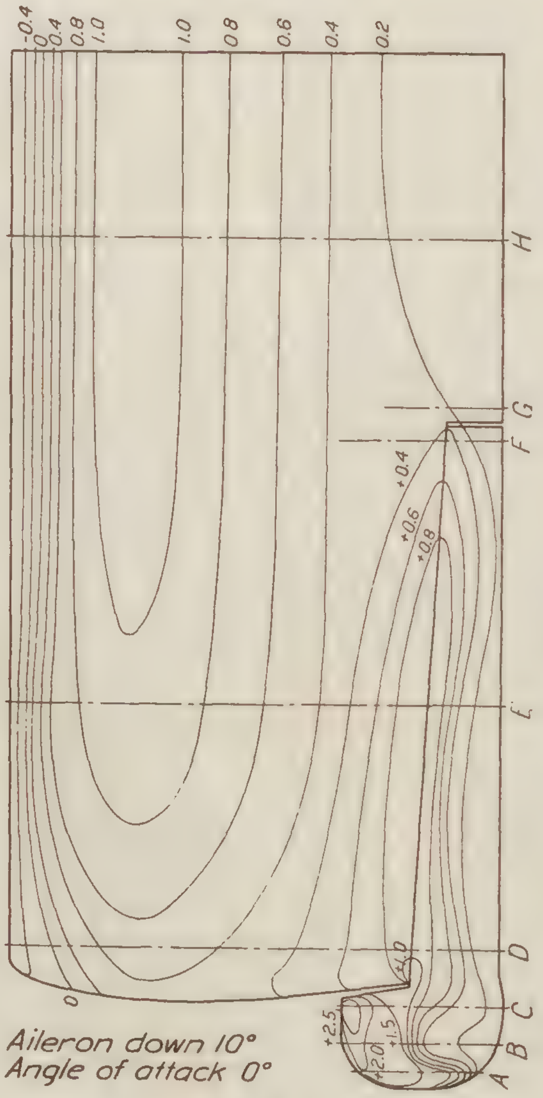


FIG. 21

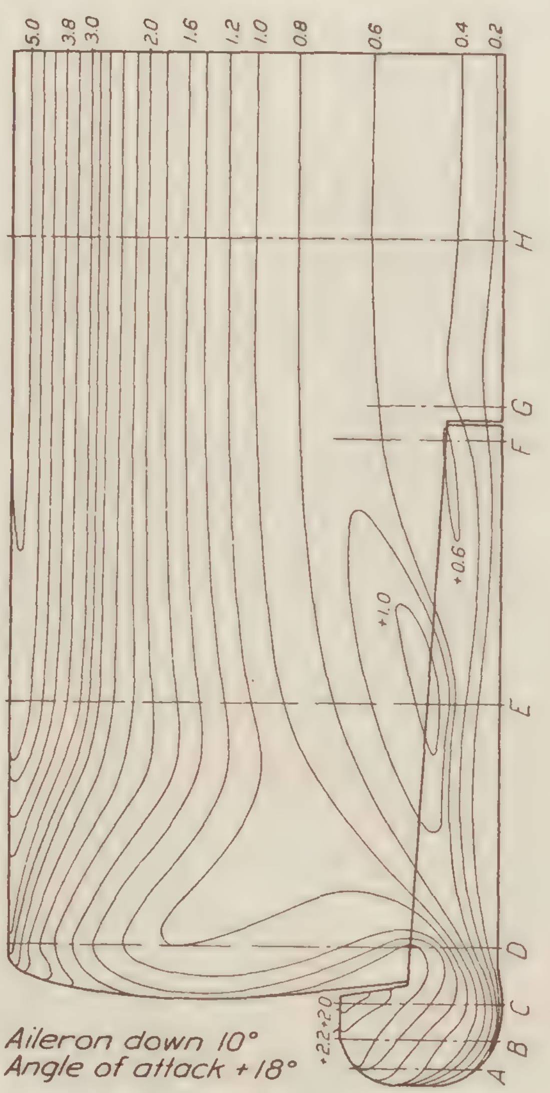


FIG. 22

Contour charts of resultant pressures in terms of q

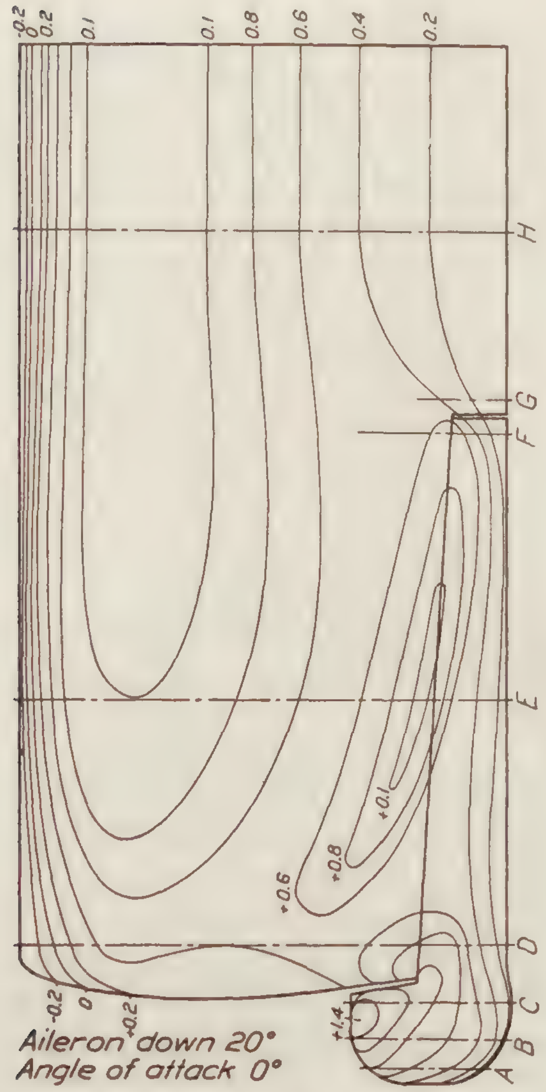


FIG. 23

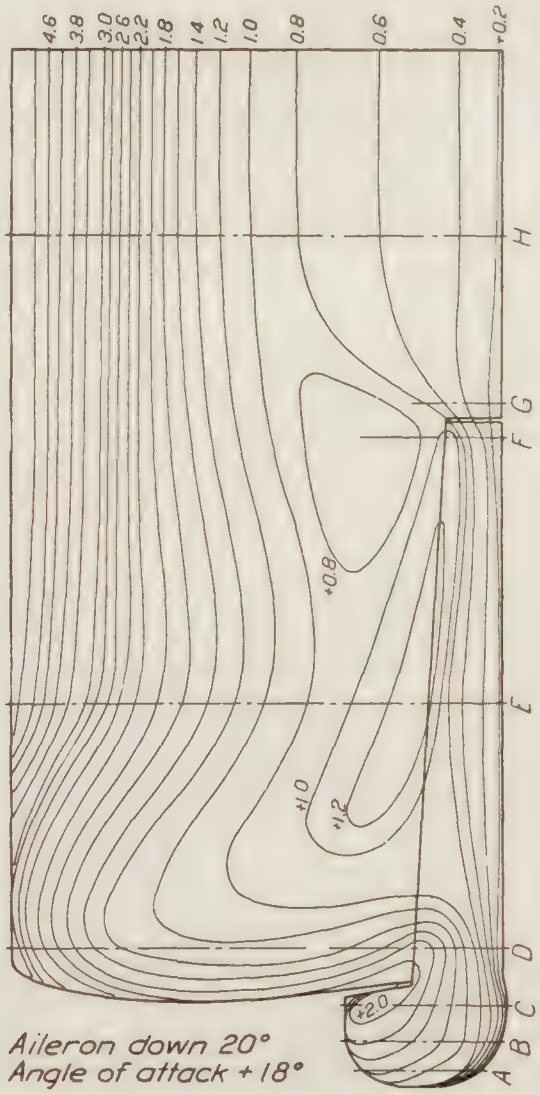


FIG. 24

Contour charts of resultant pressures in terms of *q*

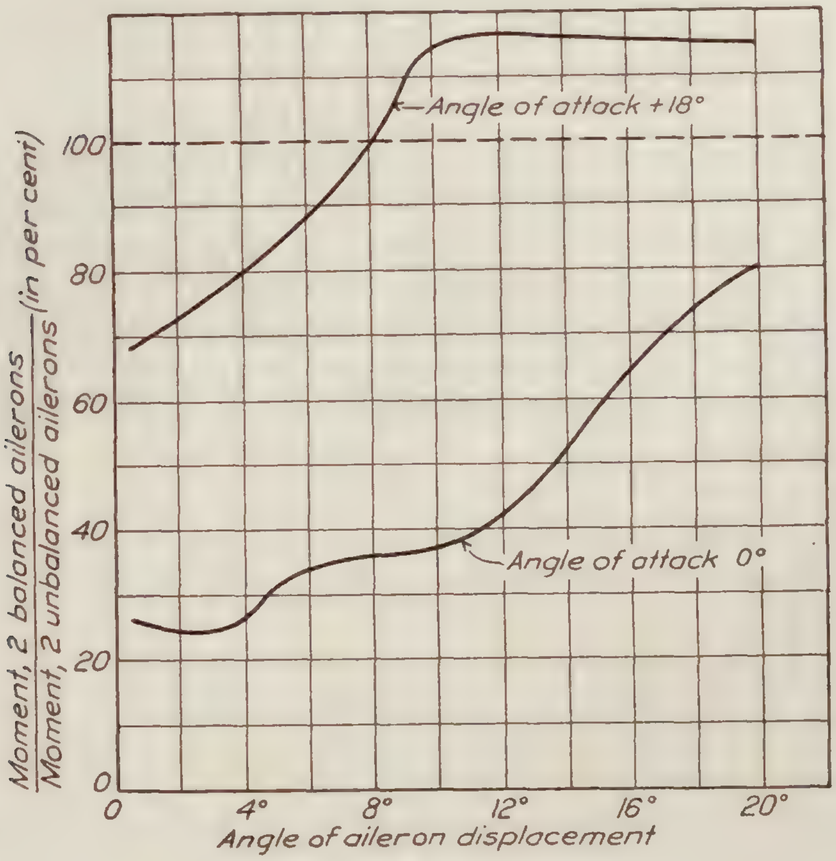


FIG. 25

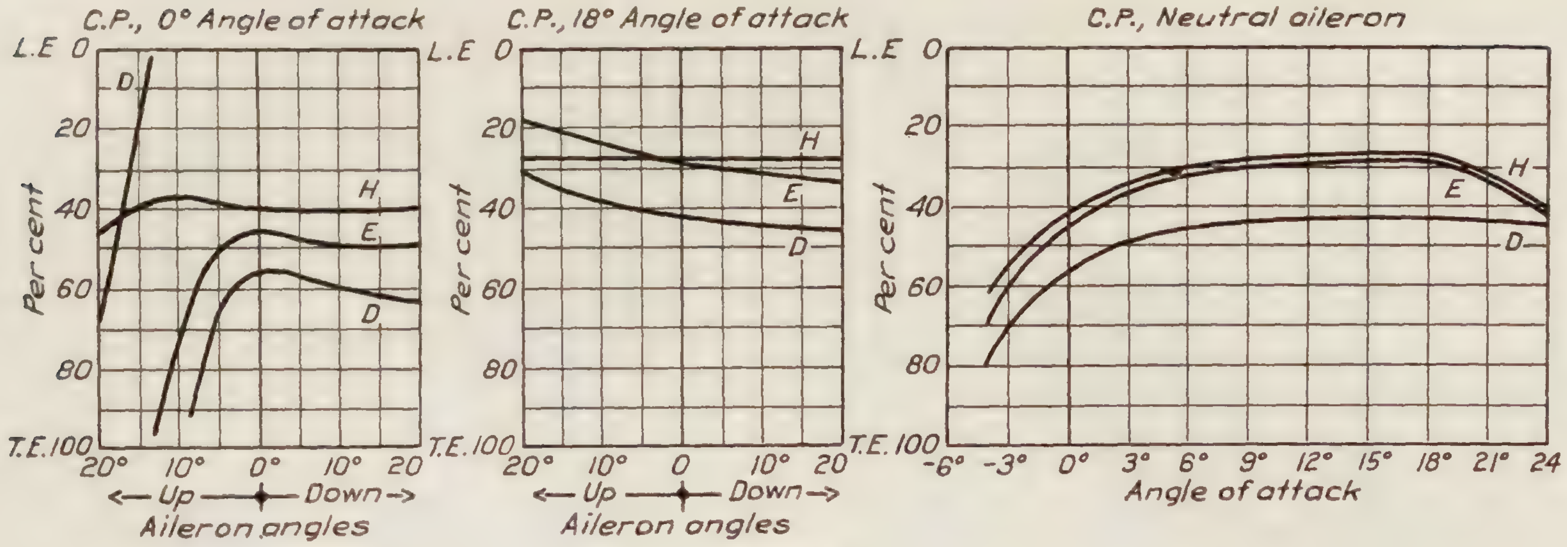


FIG. 26

CONCLUSIONS

The outstanding results of these tests may be summarized as follows:

1. The distribution of the air load along the span may be assumed for design purposes to be uniform for thick wings of rectangular plan form.
2. Tapering a wing in thickness only is not necessarily an effective method for reducing the loading toward the tip.
3. Large aileron displacements introduce important modifications of the distribution of the air load along both the chord and the span of the wing. They should be taken into account in the stress analysis and static testing of airplane wings.
4. When the wing is at a large angle of attack, the overhanging portion of the aileron usually causes burbling and therefore has a large drag.
5. The action of the aileron balance reduces the control stick force at small angles of attack for all displacements, but at large angles of attack the reverse is true for large displacements.
6. For the static testing of the overhanging portion of an aileron of this type, a loading of 35 pounds per square foot is not severe enough.

RECOMMENDATIONS

The following loading is suggested for the static testing of the overhanging portion of ailerons of this type. The total load applied should be one and one-half times the dynamic pressure (in pounds per square foot) times the area of the overhanging surface (in square feet). The dynamic pressure should correspond to the maximum speed at which the airplane is to be violently maneuvered. The load should be distributed so that the inner end of the leading edge is loaded to an intensity of two and one-half times the dynamic pressure. The loading should taper directly to an intensity equal to the dynamic pressure along the trailing edge and the tip. In these tests the aileron should be horizontal so that the load will act normal to it. The use of any type of balance on any highly maneuverable airplane is not recommended. It is further recommended that the effects of aileron displacement be given careful consideration in the design of wing structures.

REFERENCES AND BIBLIOGRAPHY

Reference 1.—Reid, E. G.: Pressure Distribution over Thick Tapered Airfoils, N. A. C. A. 81, U. S. A. 27 C Modified, and U. S. A. 35. N. A. C. A. Technical Report No. 229, 1925.

Reference 2.—Norton, F. H., and Bacon, D. L.: Pressure Distribution over Thick Airfoils—Model Tests. N. A. C. A. Technical Report No. 150, 1922.

Reference 3.—Bacon, D. L.: The Distribution of Lift over Wing Tips and Ailerons. N. A. C. A. Technical Report No. 161, 1923.

Munk, M. M.: On the Distribution of Lift Along the Span of an Airfoil with Displaced Ailerons. N. A. C. A. Technical Note No. 195, 1924.

Handbook of Instructions for Airplane Designers, Engineering Division, U. S. Army Air Service, 4th Edition, 1925.

REPORT No. 255

PRESSURE DISTRIBUTION OVER AIRFOILS AT HIGH SPEEDS

By L. J. BRIGGS and H. L. DRYDEN
Bureau of Standards

REPORT No. 255

PRESSURE DISTRIBUTION OVER AIRFOILS AT HIGH SPEEDS

By L. J. Briggs and H. L. Dryden

SUMMARY

This report deals with the pressure distribution over airfoils at high speeds, and describes an extension of an investigation of the aerodynamic characteristics of certain airfoils which was presented in N. A. C. A. Technical Report No. 207 (Reference 1). The work was carried out at the request and with the financial assistance of the National Advisory Committee for Aeronautics. A large compressor plant at Edgewood Arsenal was made available for the experiments through the courtesy of the Chemical Warfare Service.

The results presented in Report No. 207 have been confirmed and extended to higher speeds through a more extensive and systematic series of tests. Observations were also made of the air flow near the surface of the airfoils, and the large changes in lift coefficients were shown to be associated with a sudden breaking away of the flow from the upper surface.

The tests were made on models of 1-inch chord and comparison with the earlier measurements on models of 3-inch chord shows that the sudden change in the lift coefficient is due to compressibility and not to a change in the Reynolds Number. The Reynolds Number still has a large effect, however, on the drag coefficient.

The pressure distribution observations furnish the propeller designer with data on the load distribution at high speeds, and also give a better picture of the air-flow changes.

INTRODUCTION

In Technical Report 207 of the National Advisory Committee for Aeronautics an account is given of the results of some measurements by G. F. Hull and the authors of the lift, drag, and center of pressure of six airfoils at speeds ranging from 550 to 1,000 feet per second. The airfoils were of the type used by the Army Air Service in the design of wooden propellers, and the experiments showed that their aerodynamic characteristics at the speeds actually encountered in propeller blades were quite different from those at ordinary wind tunnel speeds.

The present report describes an extension of the investigation to the measurement of the distribution of pressure over the same six airfoil sections at high speeds. The object of this additional work was twofold; first, to furnish the designer with data on the load distribution at high speeds, and second, to throw some light on the changes in air flow, so that a better understanding might be gained of the effect of high speeds on the type of air flow.

The work described in Report No. 207 was carried out in an air stream 12 inches in diameter at the Lynn plant of the General Electric Co., on airfoils of 3-inch chord. It was not possible to continue the work at Lynn, because no compressor was available. Furthermore, the operating conditions at Lynn were such that it was difficult to obtain a series of observations at the same wind speed without a large expenditure of time. It was decided therefore to carry on the work at the compressor plant at Edgewood Arsenal in an air stream 2 inches in diameter and on models of 1-inch chord, the plant being made available through the courtesy of the Chemical Warfare Service. Although this change in the size of the model and the air stream had the disadvantage of changing the experimental conditions so that the results were not exactly comparable, the modification of the program has amply justified itself by the marked improvement in operating conditions and it has, in addition, given new information as to the relative importance of the viscosity and compressibility effects.

APPARATUS

Air stream.—The air stream was furnished by the 155-millimeter compressor plant at Edgewood Arsenal. This plant, which was used during the war in connection with the refrigeration of mustard gas during the process of filling gas shells, consists of four electrically-driven double-acting reciprocating compressors capable of delivering jointly about 1,800 cubic feet of free air per minute at any pressure up to 125 pounds per square inch. In the present work they were used to maintain an air stream at a speed up to 1,250 feet per second through a 2-inch orifice. The air after leaving the compressors was water-cooled and then passed through a 4-inch line in which a tank was included to damp out the pulses produced by the reciprocating motion of the compressors. About 200 feet along the line from the compressors the air passed into a vertical pipe 8 inches in diameter, with an orifice mounted at its upper end for forming the high-speed air jet. The air speeds at which observations were taken were 0.5, 0.65, 0.8, 0.95, and 1.08 times the speed of sound at the temperature of the jet, corresponding to 563, 732, 902, 1,071, and 1,218 feet per second at 20° C. The pressure and therefore the jet speed was maintained constant by a manually operated blow-off valve placed in a line connected to the ballast tank mentioned above. The values of the air speed were computed from the pressure observed on a manometer connected to a small hole in the 8-inch pipe about 2 feet ahead of the orifice mouth, the method of computation being described in the section on reduction of observations.

Orifices.—Two orifices were used. For speeds below the speed of sound a 2-inch cylindrical orifice, 1.05 inches in length, was found to give satisfactory flow conditions. For the highest speed of 1.08 times the speed of sound it was necessary to use a slightly expanding orifice to avoid large fluctuations in pressure in the stream. This orifice had a throat diameter of 1.9 inches, a length of 0.55 inches, and a taper of about 1 in 21. In each case a rounded approach was used, the section being changed from the full 8-inch diameter of the pipe to the throat diameter in a length of about 4¾ inches.

Airfoils.—The airfoil sections were the same as those described in detail in Technical Report No. 207 of the National Advisory Committee for Aeronautics but were of 1-inch chord. (Cf. figs. 4–9.) The maximum thickness was 0.10, 0.12, 0.14, 0.16, 0.18, and 0.20 inch, respectively, for the six airfoils. Because of the small thickness it was not practicable to have enough stations on one airfoil to determine the pressure distribution satisfactorily, for the forces involved were rather large and the insertion of connecting tubes necessitated the removal of a comparatively large amount of metal. For this reason seven models were required for each of the six sections. They were made by Mr. W. H. Nichols, of Waltham, Mass., and were of brass, to facilitate the necessary machining operations.

Thirteen stations were chosen as a minimum number satisfactory for determining the pressure distribution curves. Seven stations were placed on the upper surface and six on the lower, spaced close together near the leading edge where large pressure changes were to be anticipated. The locations of the stations with regard to the airfoil section are shown in Table I which gives the distance of each station from the nose, measured parallel to the chord and expressed as a fraction of the chord. The ordinates at these points are given for airfoil No. 1 of 0.10 camber ratio, and the values for the other airfoils are proportional to the camber ratio. The lower surfaces of all the airfoils were plane.

TABLE I

UPPER SURFACE

Station	Distance from nose	Ordinate for airfoil 1
1	0.025	0.041
2	0.050	0.059
3	0.100	0.079
4	0.200	0.095
5	0.400	0.097
6	0.600	0.087
7	0.850	0.045

LOWER SURFACE

8	0.050	0.000
9	0.100	0.000
10	0.200	0.000
11	0.400	0.000
12	0.600	0.000
13	0.850	0.000

Two stations were located on each of six models of each airfoil section, while one model carried only one station. The holes (about 0.025 inch in diameter) were offset one-eighth inch from the center of the airfoil, one toward either end, and connection was made through small tubing set into a groove milled in the opposite surface of the airfoil to short tubes of larger diameter soldered to the ends of the airfoil. After the tubing had been placed, the groove was filled with solder and carefully smoothed over. Figure 1 shows a number of the models with end connections.

Airfoil mounting.—A flange on the vertical 8-inch pipe carried two vertical rods, which served as supports. (See fig. 3.) The mounting for the airfoils is shown in Figure 2. The semicircular bracket B, forming the main part of the mounting, could be rotated at O about one of the vertical rods, so that the airfoil could be swung into the stream or taken out at will. The bracket carried two hollow members M rotating in plain bearings about a common horizontal axis and shaped so that the airfoil A could be clamped firmly to them at each end. The rotating members carried pointers P traveling over angular scales fastened to the bracket. A tangent screw S provided a close adjustment, and quick acting clamps C held the airfoil in position at any angle to the air stream. Rubber tubing connections to a manometer were brought in through the hollow rotating members to the short metal tubes on the ends of the airfoil.

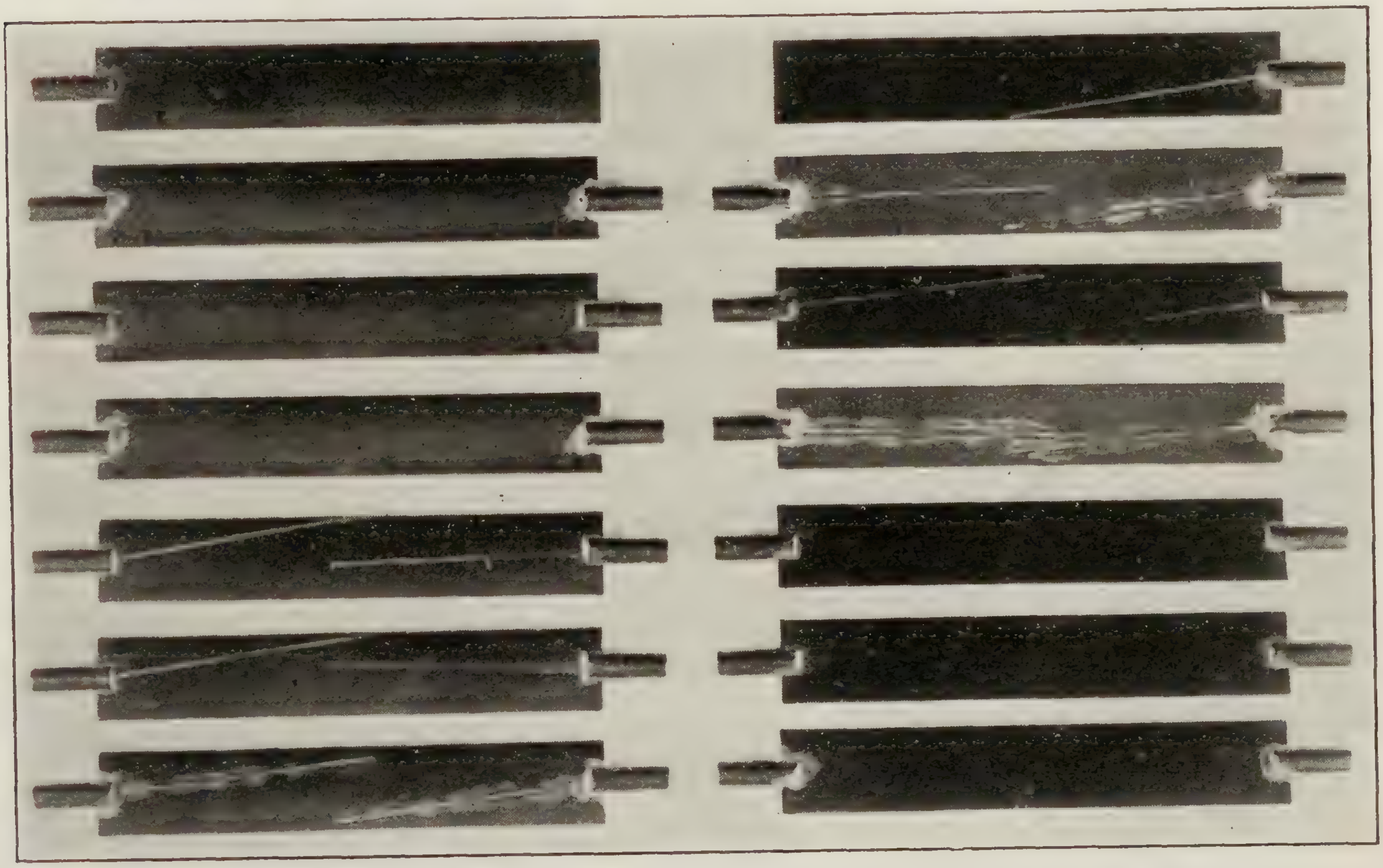


FIG. 1.—Two groups of airfoils used in the tests. The holes for measuring the pressure may be seen on airfoil 2–5, 2–4

Manometers.—The static pressure in the 8-inch pipe was measured by means of a dead-weight piston gauge or by a mercury U-tube gauge. The two instruments were connected in parallel, so that either could be used or the two compared at any time. The U-tube gauge proved better for low pressures and speeds, while the dead-weight gauge was satisfactory at the two higher speeds.

The pressure at the station on the airfoil was read on a mercury U-tube gauge of special design. The instrument was provided with markers designed to avoid parallax and so arranged that the markers could be set quickly and the actual scale readings taken subsequently while a new pressure was building up. The U-tube was also equipped at the bend with a valve which could be used to hold the mercury in position while adjustments were being made on the airfoil. The valve could also be used to damp out fluctuations by partially closing it, but this was found necessary in only a few instances.

Both pressures were measured with reference to the actual barometric pressure since static tube measurements showed that the static pressure of the stream was equal to the barometric pressure, within the experimental error. The barometric pressure was measured by a standard mercurial barometer.

Thermometers were provided to measure the air temperature in the pipe and the air temperature near the manometers and barometer.

A general view of the set-up is shown in Figure 3.

GENERAL PROCEDURE

The measurements were carried out in the following order. A model was clamped in the support and set at an angle of zero degrees to the wind stream. One station was connected to the mercury U-tube, and the connection to the other station closed. The airfoil was then swung into the air stream and the manometer allowed to come to a steady state. The valve on the manometer was then closed and the observer at the manometer adjusted the markers while the observer at the airfoil turned the airfoil to a new angle. After the markers were set, the first observer opened the manometer valve and read the position of the markers and recorded them while equilibrium in the new condition was being established. Measurements were made for this one station at the lowest speed at 4° intervals from $-20°$ to $+24°$. The second station was then connected and the first closed off and measurements made over the same range of angles. The airfoil was then removed and a replica with two other stations carried through the same range, this process being continued until all 13 stations on one section had been covered at one speed, a total of 156 observations.

The remaining five sections were tested at the same speed, making 936 observations, and then the whole series was repeated for each of the remaining four speeds, giving 4,680 observations in all. Where necessary, additional observations were interpolated.

An assistant kept the pressure in the 8-inch pipe constant by hand regulation of the blow-off valve and thus, as will be shown later, kept the value of the ratio of the air speed to the speed of sound constant at the desired value.

REDUCTION OF OBSERVATIONS

Notation.—

p = absolute pressure at a station on the airfoil.
p_1 = absolute static pressure inside pipe (velocity pressure negligible).
p_o = absolute static pressure in jet (equal to barometric pressure).
$p_1 - p_o$ = impact pressure.
V = the speed of air in jet.
c = speed of sound at temperature of jet.
ρ = density of air in jet.
μ = viscosity of air in jet.
$q = \frac{1}{2}\rho V^2$ = velocity pressure.
l = linear dimension determining the scale (chord of airfoil).
J = mechanical equivalent of heat.
C_p = specific heat of air at constant pressure.
k = ratio of specific heats.
T_1 = absolute temperature in pipe before expansion.
T_o = absolute temperature in jet after expansion.

Pressure on airfoils.—The results of the pressure measurements are expressed in terms of the nondimensional or absolute coefficients of the type described in Report 207 of the National Advisory Committee for Aeronautics. The principle of dimensional homogeneity indicates that the pressure difference $p - p_o$ is equal to the velocity pressure, $q = \frac{1}{2}\rho V^2$, times a function of the Reynolds Number $Vl\rho/\mu$ and the compressibility variable V/c. In other words

$$\frac{p-p_o}{\frac{1}{2}\rho V^2} = \frac{p-p_o}{q} = f\left(\rho\frac{Vl}{\mu},\ \frac{V}{c}\right)$$

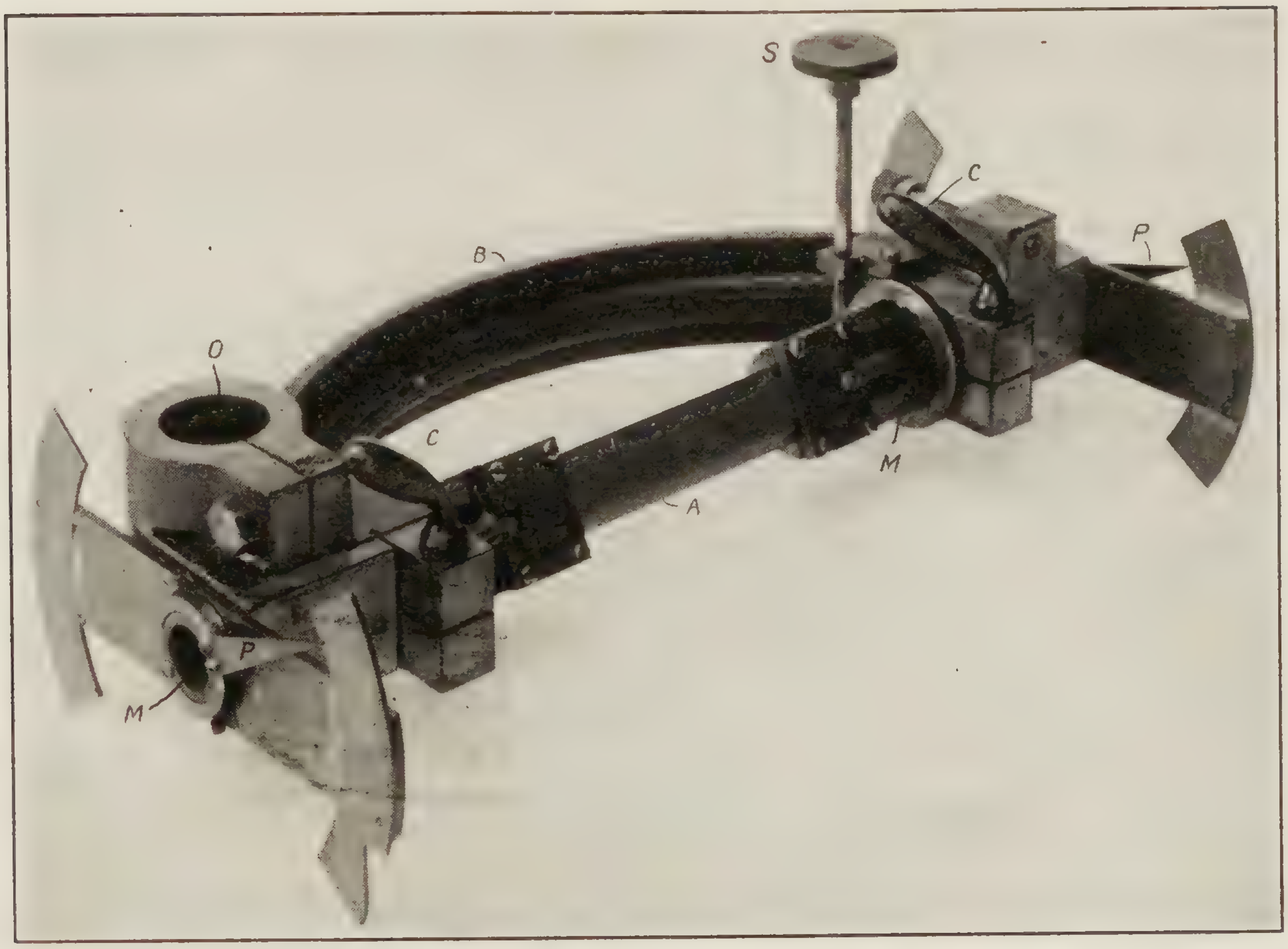


FIG. 2.—The apparatus for holding the airfoil

FIG. 3.—General view of apparatus. Gauges for speed measurement and control valves at the left, airfoil mounting in the center, gauge for pressure distribution at the right

As will be shown in the next paragraph q is equal to the measured pressure in the 8-inch pipe times a factor which depends only on the speed ratio, $\frac{V}{c}$. Both p and the pipe pressure are measured on mercury manometers at nearly the same temperature for the three low speeds so that the ratio may be taken directly without further reduction. For the two high speeds the reading of the dead-weight gauge is first reduced to cm. of Hg. Values of $\frac{p-p_o}{q}$ are then obtained by multiplying by the appropriate factor of Table II.

Speed ratio.—The speed ratio is computed from the pressure of the air in the pipe before expansion on the assumption that the expansion through the orifice is isentropic, that air is an ideal gas, and that the pressure in the jet just outside the orifice is equal to the barometric pressure. The first assumption is substantiated by the experimental fact that for speeds below the speed of sound an impact tube in the jet gives a pressure which balances the pressure on an impact tube in the pipe within very close limits. Hence there is no appreciable dissipation of energy by resistance or heat conduction, during the expansion through the nozzle and the recompression ahead of the impact tube in the jet. The third assumption is substantiated by static tube measurements in the jet.

The formula for the speed computed on these assumptions is

$$V^2=2JC_pT_i\left\{1-\left(\frac{p_o}{p_i}\right)^{\frac{k-1}{k}}\right\}=2JC_p(T_i-T_o) \tag{1}$$

Now the velocity of sound c is proportional to the square root of the absolute temperature; hence if c_o is the value under standard conditions, as for example at 0° C,

$$c=c_o\sqrt{\frac{T_o}{273}}$$

Since

$$T_o=T_i\left(\frac{p_o}{p_i}\right)^{\frac{k-1}{k}}$$

$$c^2=\frac{c_o^2T_i}{273}\left(\frac{p_o}{p_i}\right)^{\frac{k-1}{k}}$$

Dividing equation (1) by c^2

$$\frac{V^2}{c^2}=\frac{546JC_p}{c_o^2}\left\{\left(\frac{p_i}{p_o}\right)^{\frac{k-1}{k}}-1\right\} \tag{2}$$

V/c therefore depends only on the absolute pressure ratio and not on the temperature T_i.

The values of p_i-p_o corresponding to a definite value of V/c vary slowly with changes in the barometric pressure, p_o, but it was found quite feasible to make allowance for this variation and carry out all measurements at the same value of V/c. The effect of change of the density of mercury with temperature was well within the general precision of the work.

Attention has been called to the fact that the velocity pressure $\frac{1}{2}\rho V^2$ may be readily computed from the observed pressure, p_i-p_o. In fact

$$\rho=\frac{p_o}{T_o}\,\frac{288\times0.0012255}{1\ 013\ 300}$$

where ρ is the density in gm/cm², p_o the barometric pressure in dynes/cm² and T_o the absolute temperature in °C. Hence

$$\frac{1}{2}\rho V^2=\frac{288\times0.0012255}{1\ 013\ 300}\,JC_pp_o\left\{\left(\frac{p_i}{p_o}\right)^{\frac{k-1}{k}}-1\right\}$$

Substituting for the quantity in the brackets its equivalent from equation (2)

$$\frac{1}{2}\rho V^2 = 3.5088\ p_o\ (0.19991\ V^2/c^2)$$

Therefore

$$\frac{p_i-p_o}{\frac{1}{2}\rho V^2} = \frac{\frac{p_i}{p_o}-1}{3.5088\times 0.19991\frac{V^2}{c^2}} = \frac{\left(1+0.19991\frac{V^2}{c^2}\right)^{7/2}-1}{3.5088\times 0.19991\frac{V^2}{c^2}} \tag{3}$$

a result dependent only on V/c. Values for the speeds used are given in Table II and by their aid the results given in the paper for $\frac{p-p_o}{\frac{1}{2}\rho V^2}$ can be recomputed to give ratios to impact pressure p_i-p_o if desired.

TABLE II

$\frac{V}{c}$	$\frac{p_i-p_o}{\frac{1}{2}\rho V^2}$
0.50	1.061
0.65	1.107
0.80	1.170
0.95	1.244
1.08	1.325

The tables in the appendix to this report and the curves of Figures 4 to 9 give the values of $\frac{p-p_o}{\frac{1}{2}\rho\ V^2}$ for the 13 stations on each of the six airfoil sections at the five values of $\frac{V}{c}$.

INTEGRATION OF PRESSURES

For comparison with the earlier results it is necessary to compute values of the total forces and moments, i. e., the lift coefficients, drag coefficients, and center of pressure coefficients as defined in Report 207.[1]

It is inconvenient to determine the lift and drag coefficients directly and therefore the normal force and tangential force coefficients, C_N and C_T are first computed, the normal force being defined as the force normal to the chord of the airfoil (whereas the lift is normal to the wind direction) and the tangential force as the force parallel to the chord (whereas the drag is parallel to the wind direction). The lift and drag coefficients, C_L and C_D, follow immediately from the relations

$$C_L = C_N \cos\alpha - C_T \sin\alpha$$
$$C_D = C_N \sin\alpha + C_T \cos\alpha$$

where α is the angle of attack.

Forces computed from the observed pressures can not take account of the effects of skin friction, since only the pressure normal to the surface is measured by the method described. It is to be expected, therefore, that the forces computed from the pressures will differ somewhat from the directly measured forces, especially in the case of the drag component.

The method of determining the normal and tangential force coefficients from the pressures normal to the surface reduces to the determination of the area of two curves, one in which the observed pressures are plotted as ordinates and distances of the station parallel to the chord

---

[1] $$C_L = \frac{\text{Lift}}{\frac{1}{2}\rho\ V^2\ \text{Area}}$$
$$C_D = \frac{\text{Drag}}{\frac{1}{2}\rho\ V^2\ \text{Area}}$$

Center of pressure coefficient = distance center of pressure to leading edge measured parallel to chord divided by chord length.
Moment coefficient = $(C_L \cos\alpha + C_D \sin\alpha)$ times center of pressure coefficient
α = angle of attack.

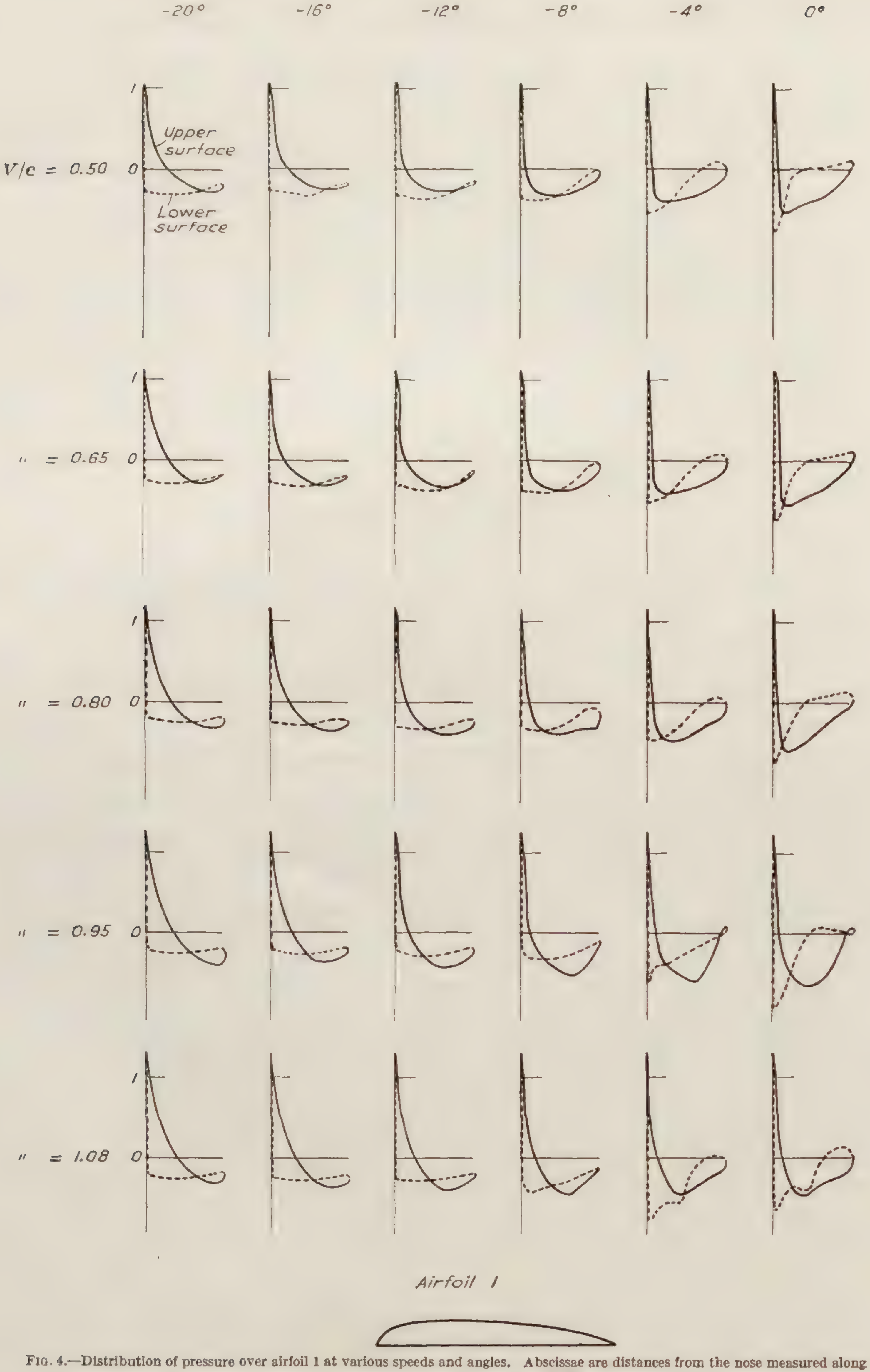


FIG. 4.—Distribution of pressure over airfoil 1 at various speeds and angles. Abscissae are distances from the nose measured along the chord. Ordinates are values of $\frac{p-p_0}{\frac{1}{2}\rho V^2}$

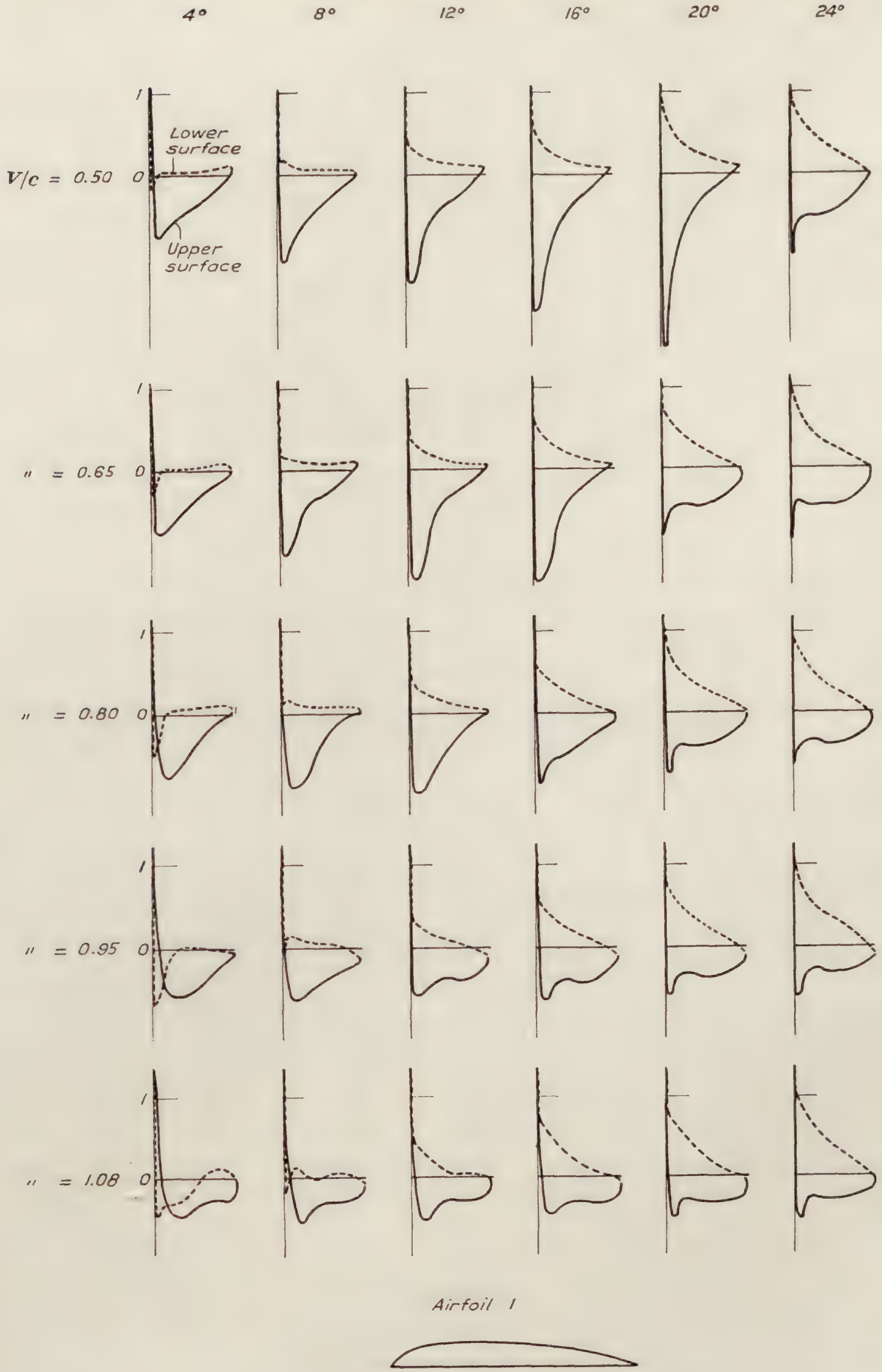


FIG. 4.—Continued

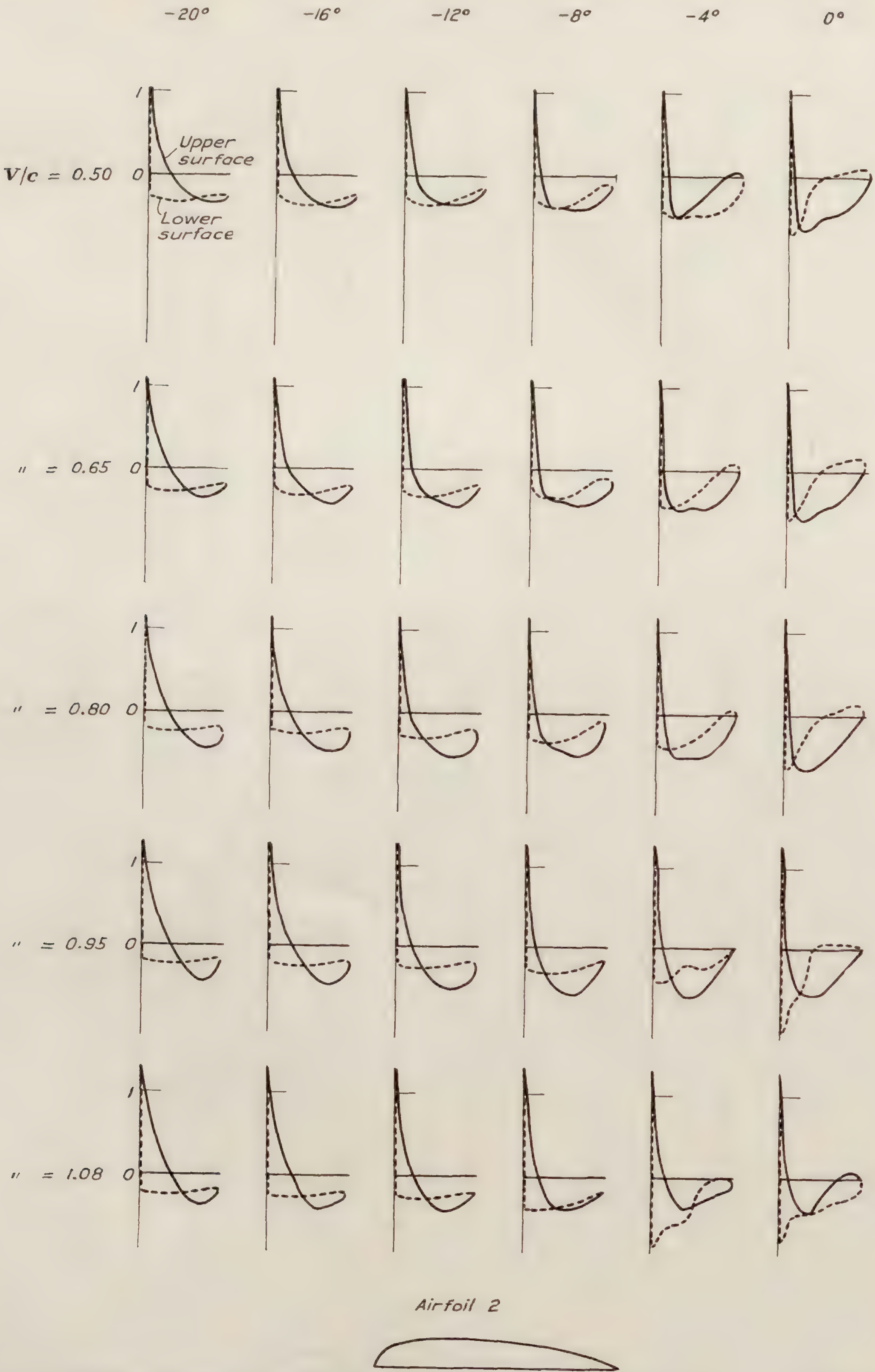


FIG. 5.—Distribution of pressure over airfoil 2 at various speeds and angles. Abscissae are distances from the nose measured along the chord. Ordinates are values of $\frac{p-p_0}{\frac{1}{2}\rho V^2}$

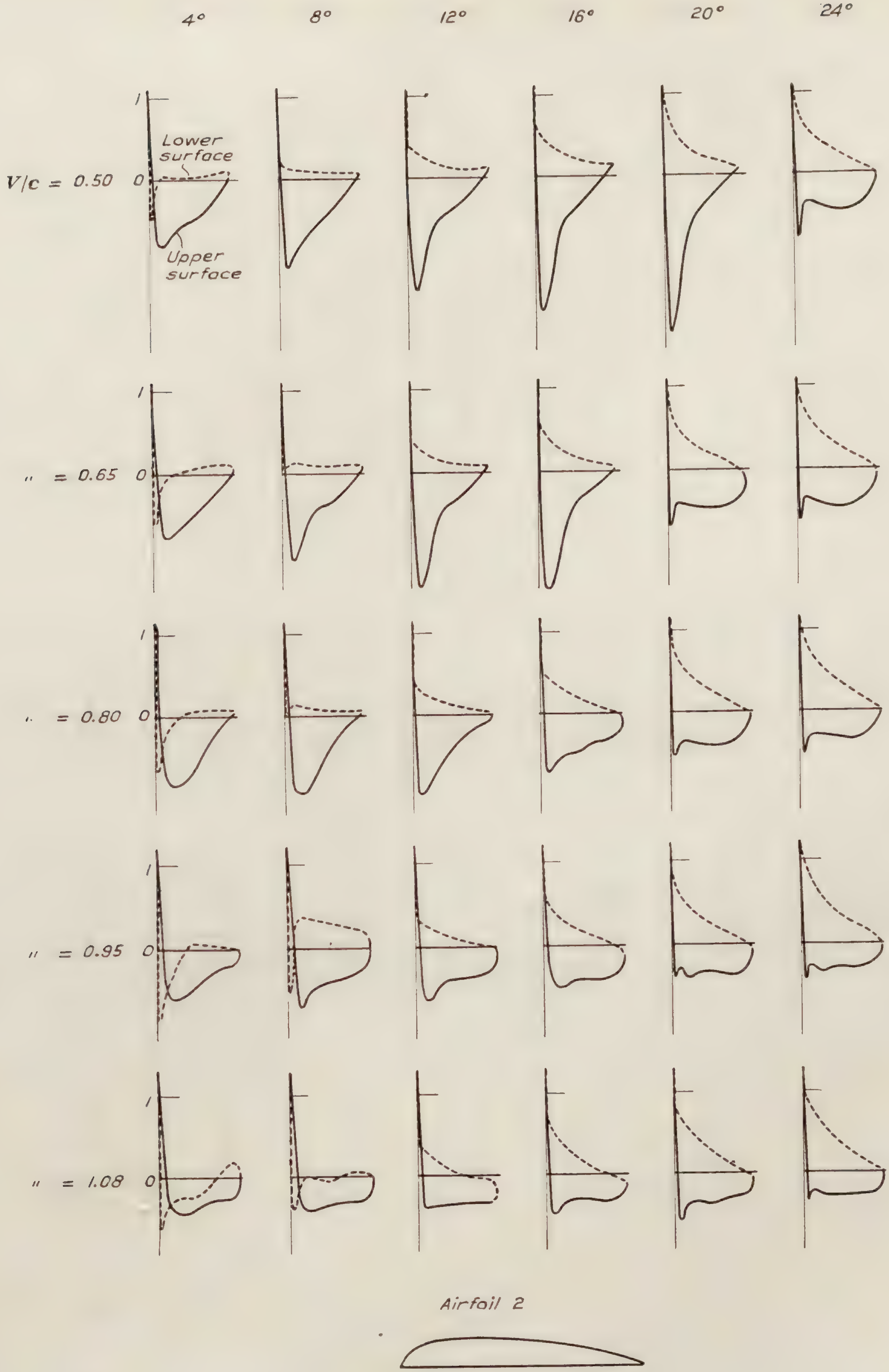


Fig. 5.—Continued

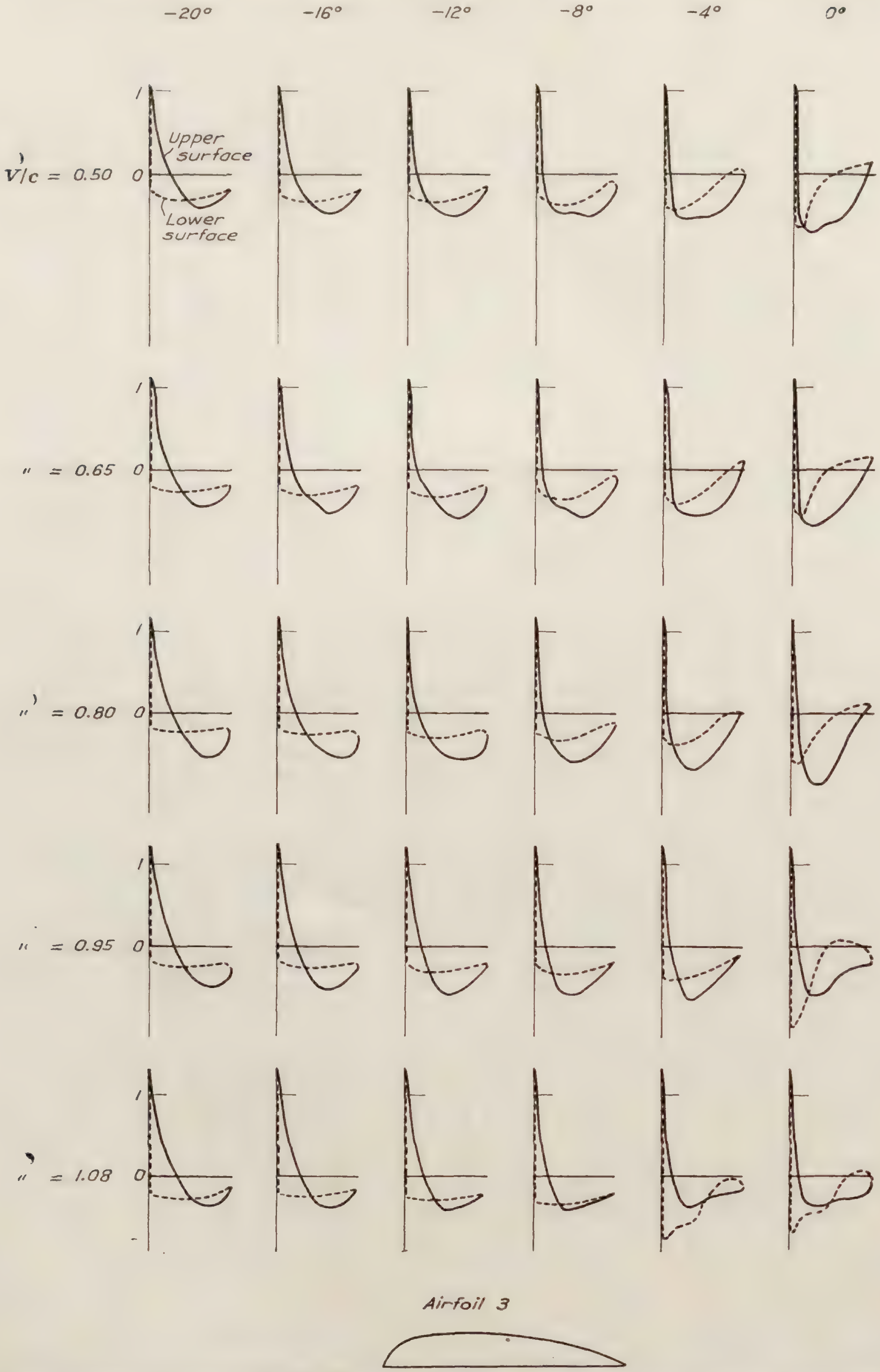


FIG. 6.—Distribution of pressure over airfoil 3 at various speeds and angles. Abscissae are distances from the nose measured along the chord. Ordinates are values of $\frac{p-p_0}{\frac{1}{2}\rho V^2}$

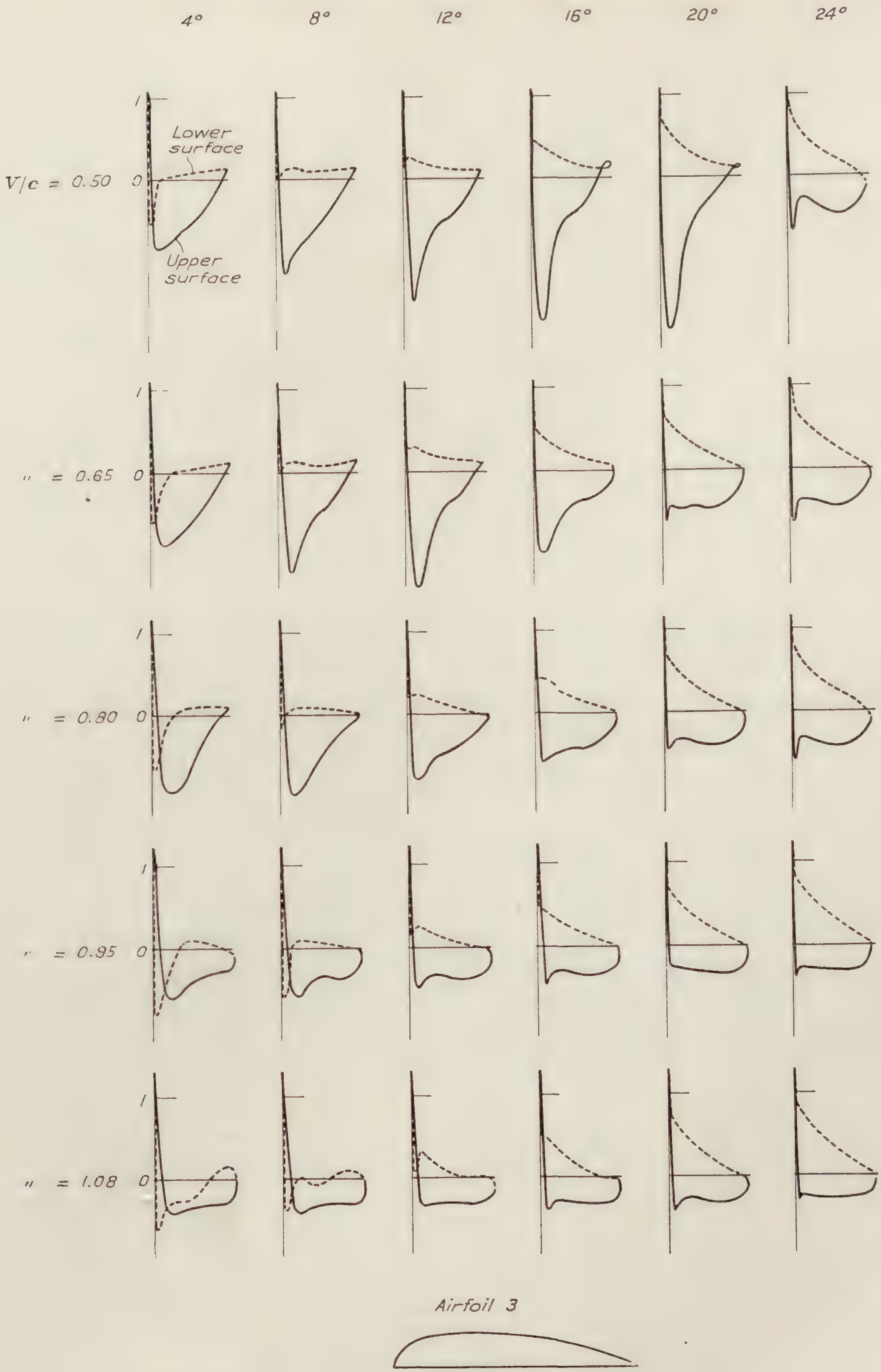


FIG. 6.—Continued

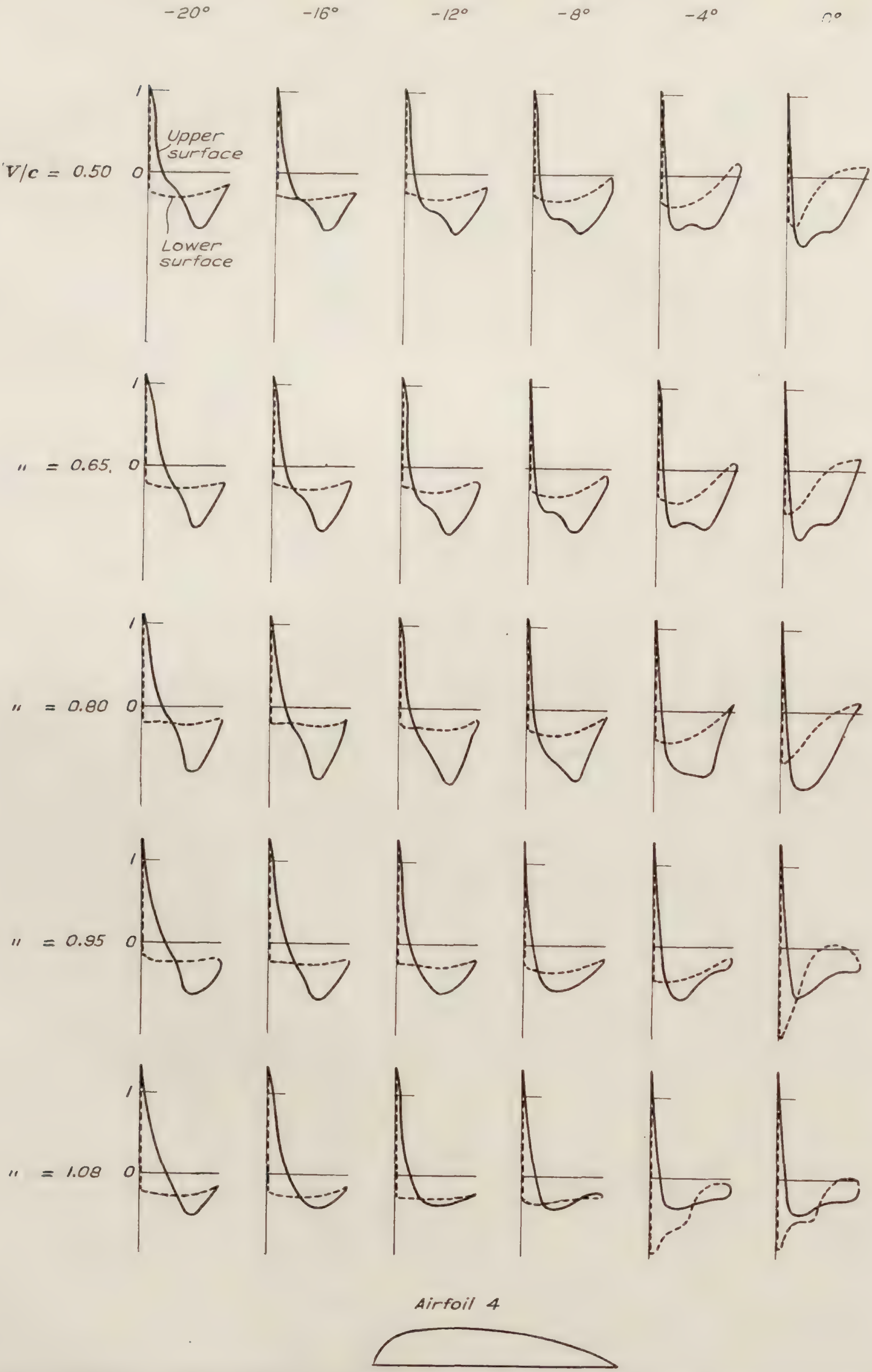


FIG. 7.—Distribution of pressure over airfoil 4 at various speeds and angles. Abscissae are distances from the nose measured along the chord. Ordinates are values of $\frac{p-p_0}{\frac{1}{2}\rho V^2}$

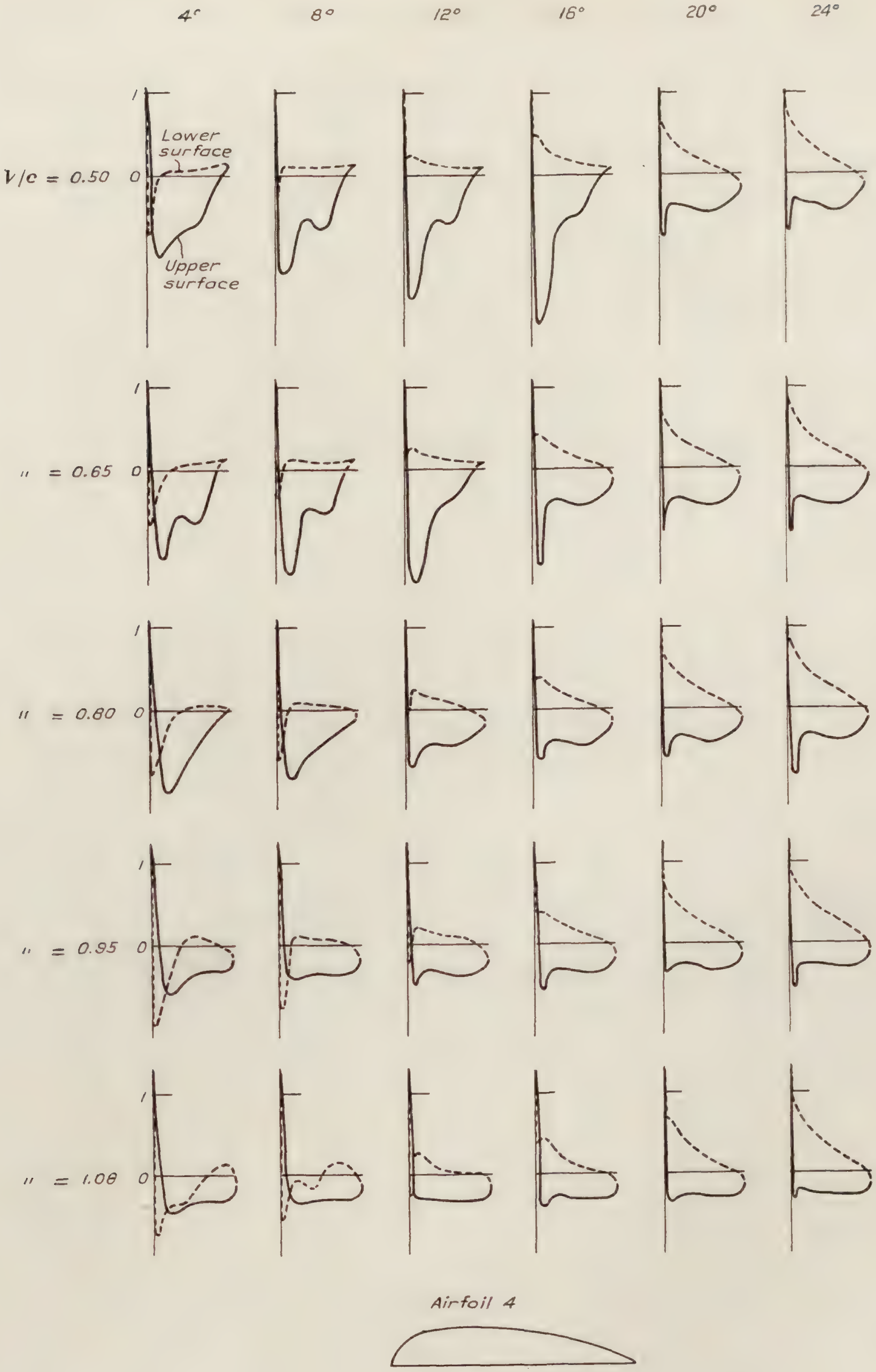


FIG 7.—Continued

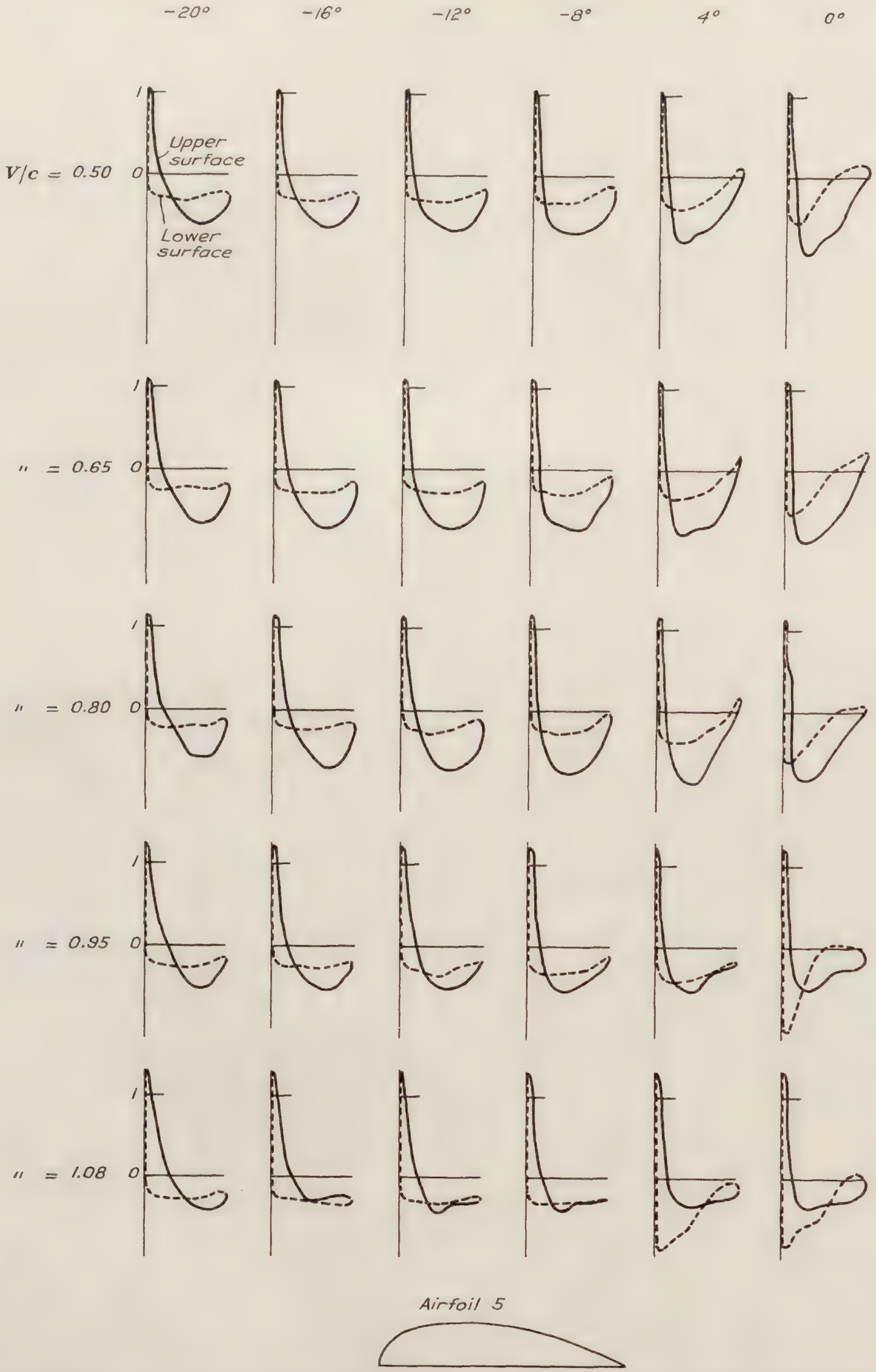


Fig. 8.—Distribution of pressure over airfoil 5 at various speeds and angles. Abscissae are distances from the nose measured along the chord. Ordinates are values of $\frac{p-p_0}{\frac{1}{2}\rho V^2}$

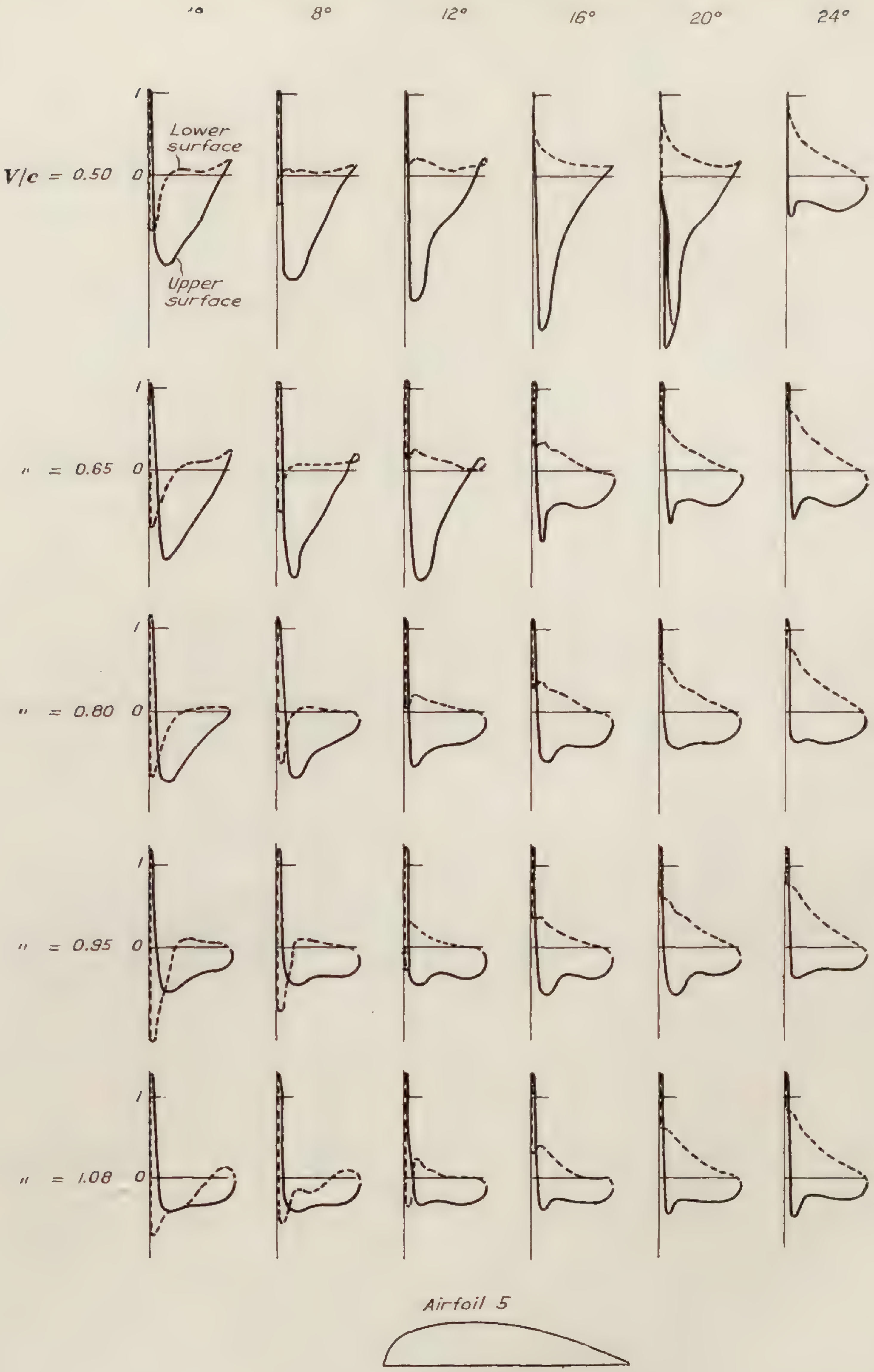


FIG. 8.—Continued

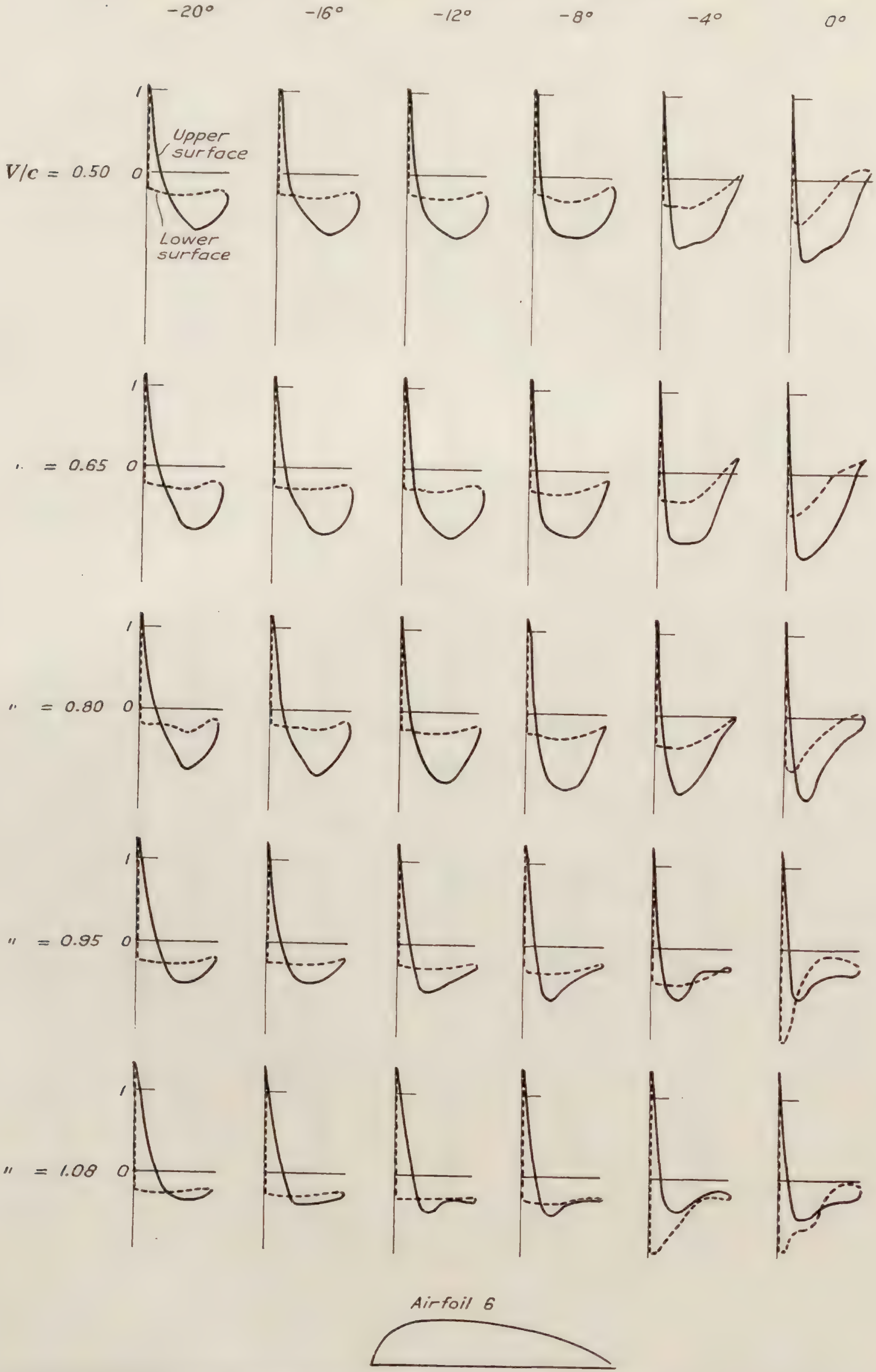


FIG. 9.—Distribution of pressure over airfoil 6 at various speeds and angles. Abscissae are distances from the nose measured along the chord. Ordinates are values of $\frac{p-p_0}{\frac{1}{2}\rho V^2}$

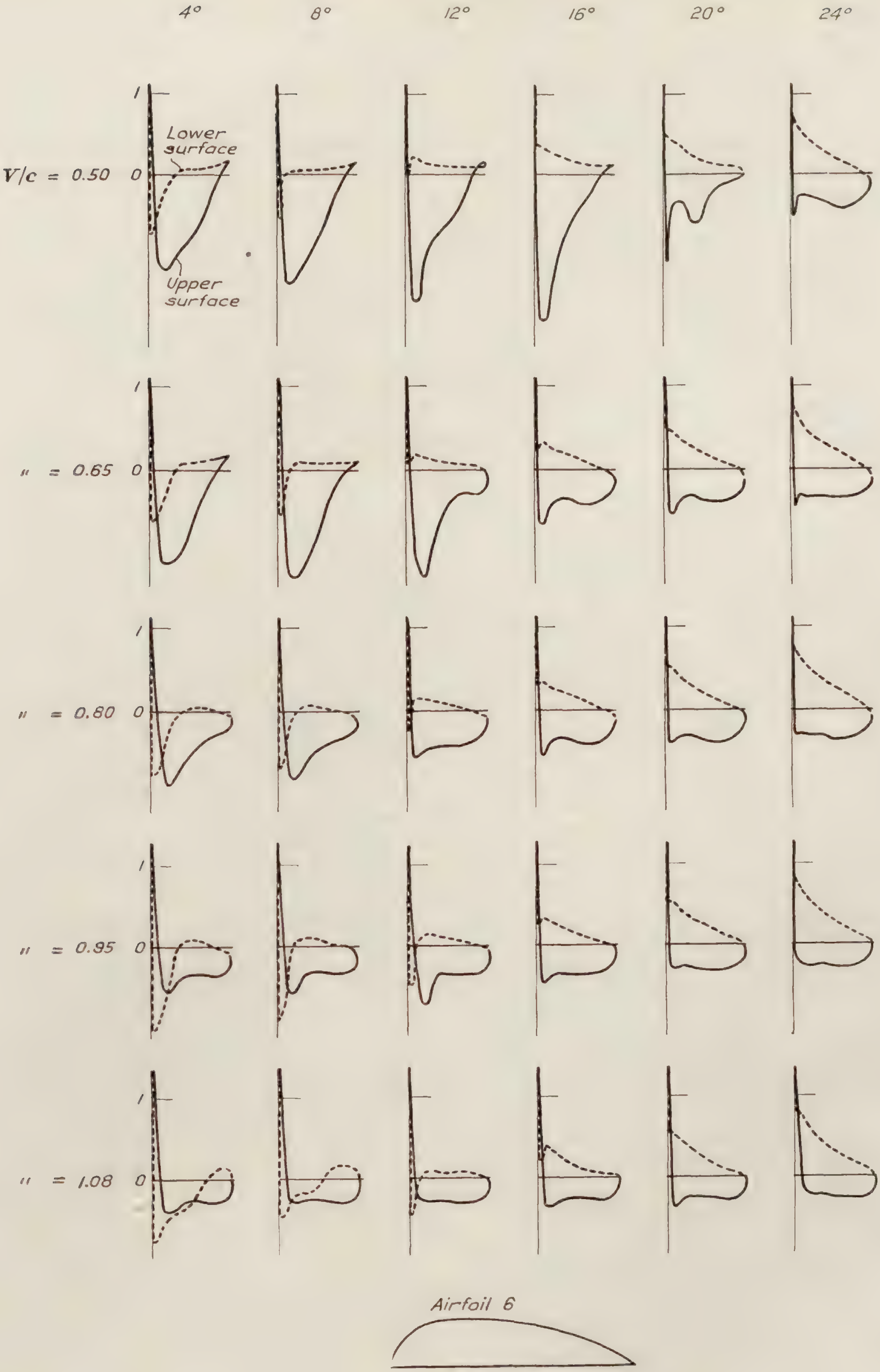


FIG. 9.—Continued

as abscissae and the second in which the ordinates are the same but the abscissae are distances perpendicular to the chord. The proof of this statement is obvious from Figure 10. The curves are of course determined by the values of the ordinates at a few discrete values of the abscissae. The usual method of finding the area is a graphical one of drawing in a faired curve and measuring the area with a planimeter or by counting small squares on coordinate paper. In the present case because of the large number of observations to be treated, a numerical method was found more satisfactory since it was much quicker and gave results which were more directly comparable.[2]

In the integration for the tangential force coefficient it was found desirable to interpolate additional pressure values at the ends since no stations could be placed close to the leading and trailing edge. Table III gives the factors for airfoil 1 of 0.10 camber ratio. The normal force factors are the same for all airfoils but the tangential force factors are proportional to the thickness of the airfoil, those for airfoil 2 being 1.2 times those for airfoil 1 and so on. It will be noted that the signs for the upper surface in the case of the normal force factors and for the rear of the upper surface in the case of the tangential force factors are negative, because a positive pressure acting on those parts of the airfoil produces negative forces, the normal force being called positive when directed from the lower surface to the upper and the tangential force being called positive when directed from leading to trailing edge. The lower surface does not contribute to the tangential force since it is flat.

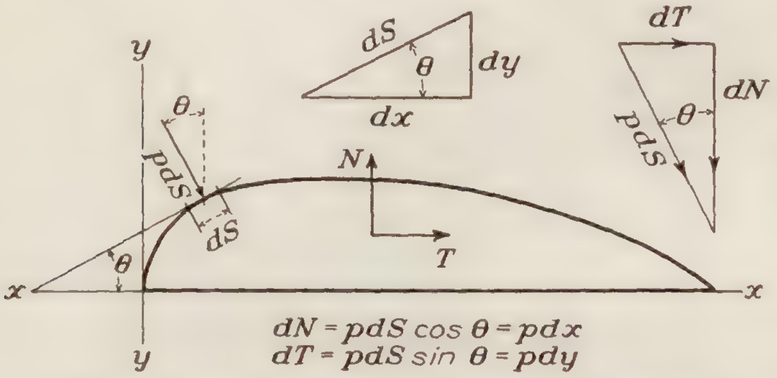


FIG. 10.—Diagram showing method of computing normal and tangential forces from the observed pressures

TABLE III

Station	Factors for normal force coefficient for all airfoils	Factors for tangential force coefficient for airfoil 1 only
Interpolated station at leading edge		0.0154
1	−0.0476	.0464
2	−.0119	−.0003
3	−.0706	.0330
4	−.1684	.0056
5	−.2251	−.0085
6	−.1500	−.0180
7	−.3264	−.0580
Interpolated station at trailing edge		−.0155
8	.0952	0
9	.0289	0
10	.1744	0
11	.2251	0
12	.1500	0
13	.3264	0

The values of the lift and drag coefficients obtained are shown in Figures 11 and 12 and in the tables in the appendix.

The moments about the leading edge and the positions of the center of pressure were computed by an approximate method. The approximation consisted first in the neglect of the moments of the components of the pressure parallel to the chord and second in the use of factors obtained by multiplying the normal force factor for a given station by the distance of the station from the nose. The errors arising from this procedure will be discussed in the section on "Accuracy."

The values of the approximate moment coefficients and center of pressure positions are given in the appendix and in Figures 13 and 14.

---

[2] Many such numerical methods of integration are described in textbooks on applied mathematics. In the present case a curve of the third degree was passed through four adjacent points, the ordinates being denoted by letters and the numerical values of the abscissae inserted. The area between the two inner ordinates, the curve, and the axis of abscissae was found by integration. At the end intervals special treatment was necessary and in general the procedure followed was to pass a curve of the second degree through the three end points and to integrate from the second point to the end of the airfoil. When this procedure is carried out and the results for all intervals added, there results a series of factors by which each ordinate is to be multiplied and the results of the multiplication summed for all stations to obtain the area.

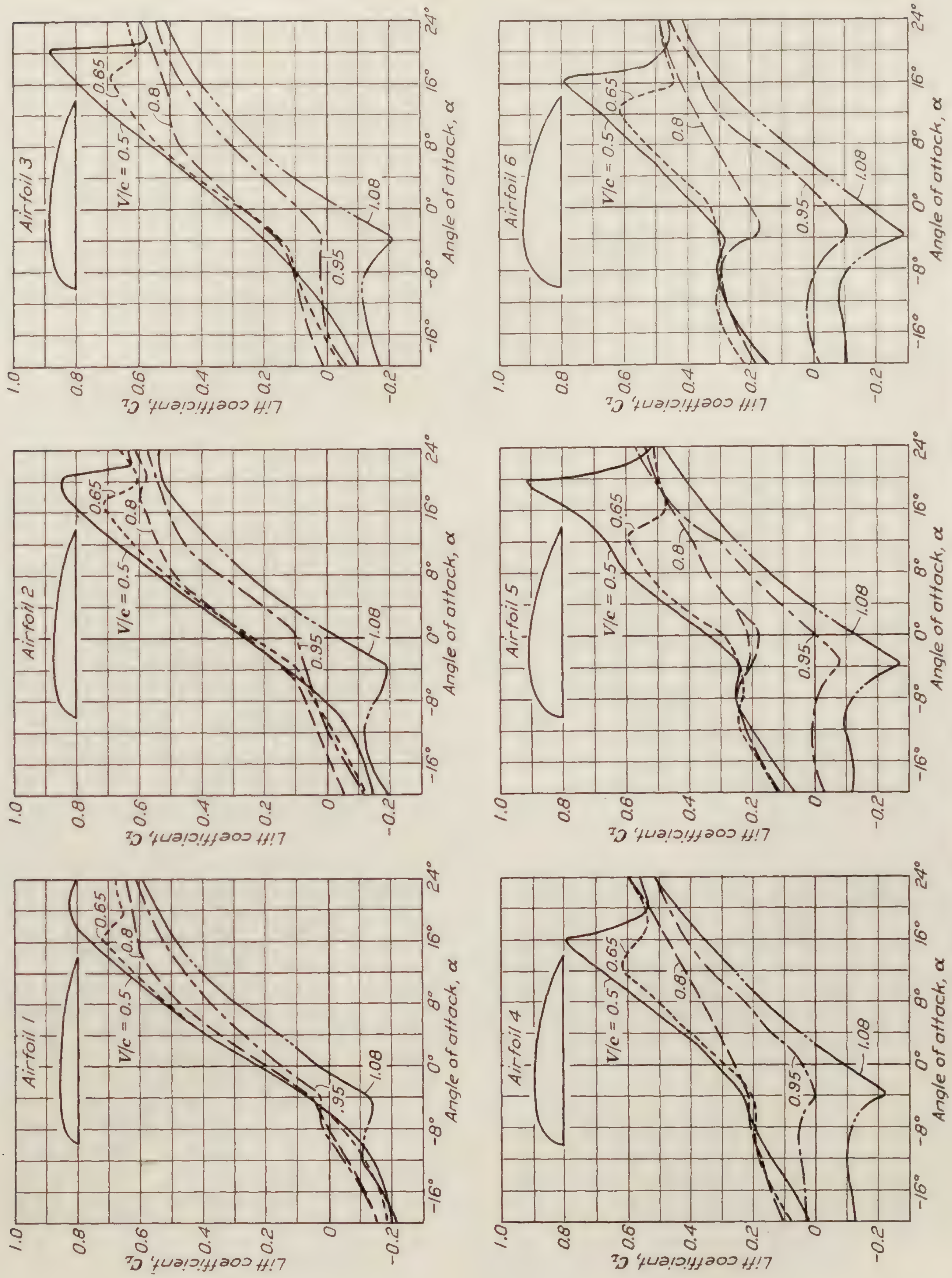


FIG. 11.—Lift coefficients for the six airfoils at various speeds and angles. Numbers on the curves denote values of V/c

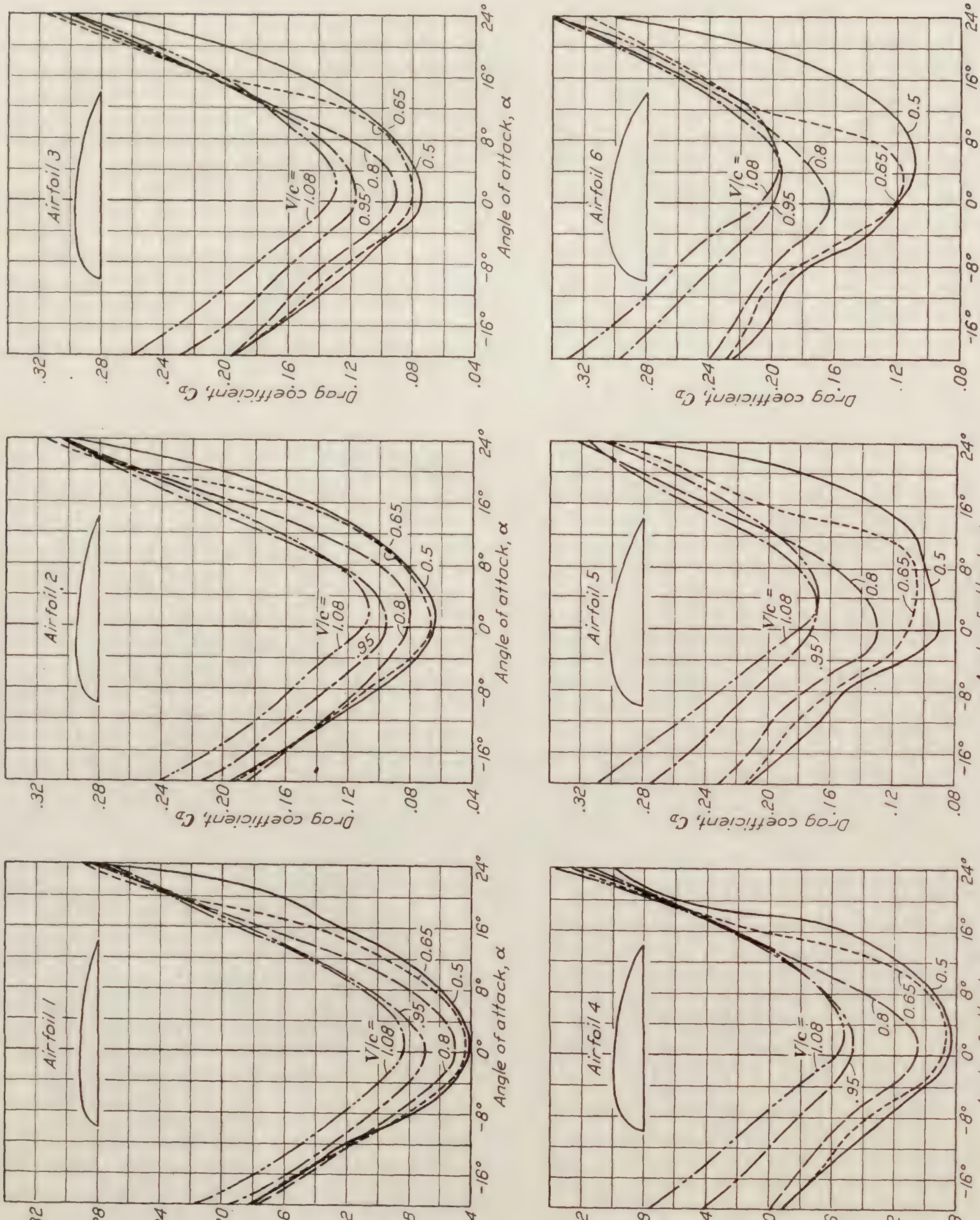


FIG. 12.—Drag coefficients for the six airfoils at various speeds and angles. Numbers on the curves denote values of V/c

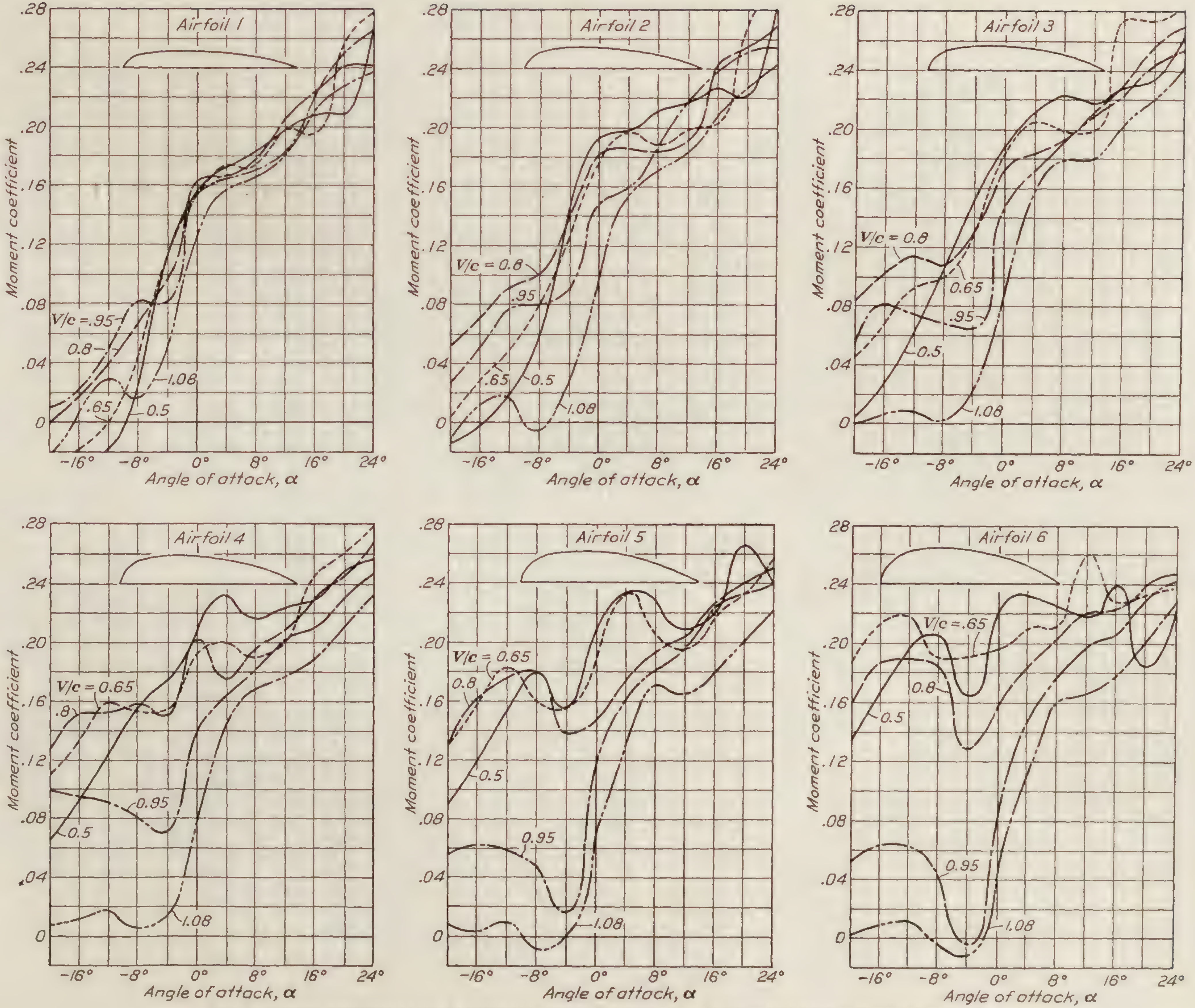


FIG. 13.—Moment coefficients for the six airfoils at various speeds and angles. Numbers on the curves denote values of V/c

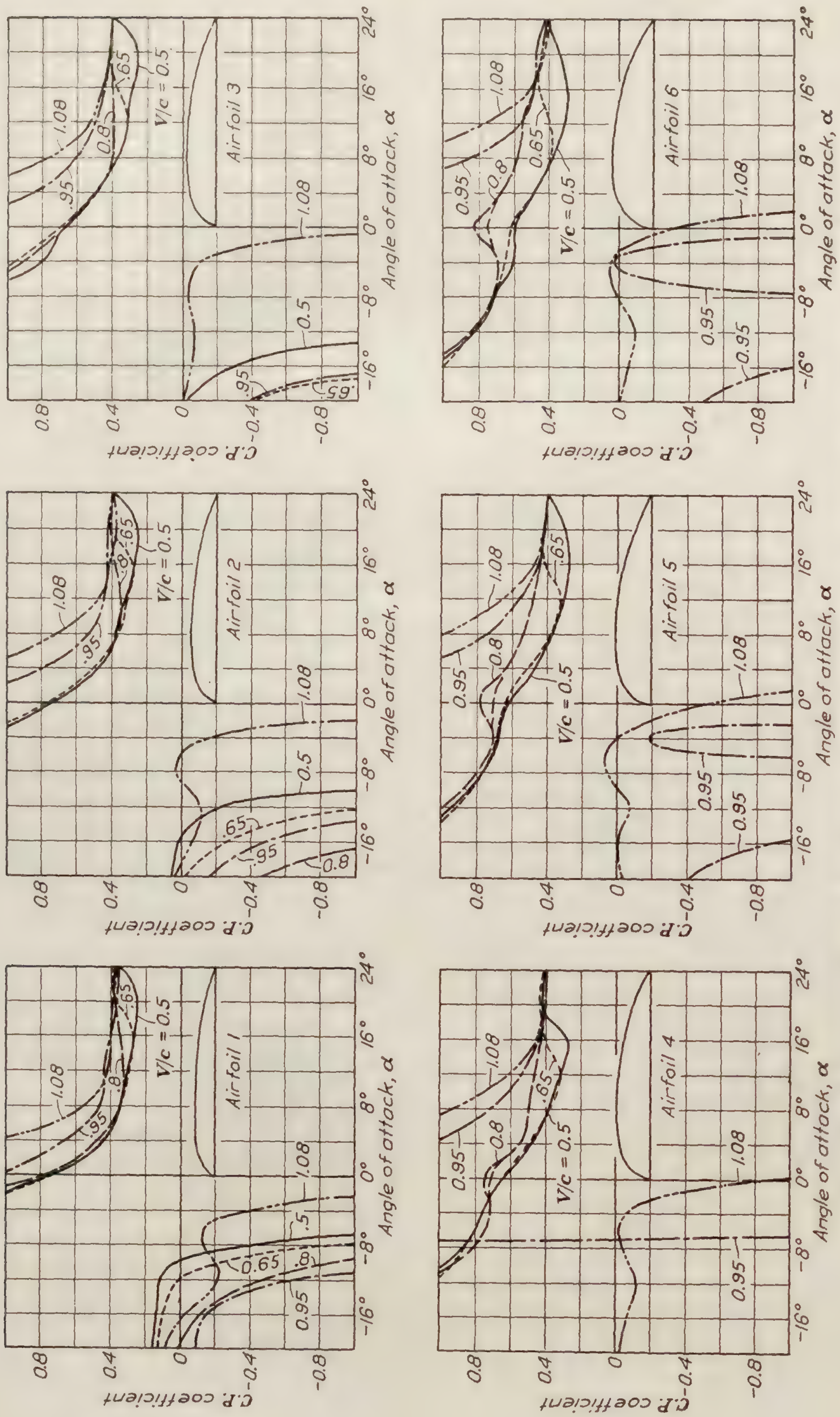


FIG. 11.—Center of pressure coefficients for the six airfoils at various speeds and angles. Numbers on the curves denote values of V/c

EFFECTS OF POSITION OF AIRFOIL IN AIR STREAM AND OF THE SIZE OF THE AIR STREAM

A number of auxiliary measurements were made in order to find the effects of variations in the experimental conditions as regards the position of the model in the air stream and the size of the air stream. The complete series of tests was carried out with the center of the airfoil at a height of 4 inches above the plane of the orifice mouth in air streams of approximately 2 inches in diameter. The measurements on airfoil 3 were repeated for a number of stations at speeds of 0.8 and 0.95 times the speed of sound at a distance of 2 inches above the plane of the orifice mouth. Typical curves are shown in Figure 15. It will be noted that in general the agreement is very good, the greatest difference being near 0° for station 8 at 0.8 speed where the curves for the two heights are shifted with respect to each other. The effect is less marked for the same station at 0.95 speed. In fact the flow around airfoil 3 at 0. 8 speed at negative angles is rather unstable and in one instance (not shown) a somewhat larger difference was found at large negative angles. In general we may say that a change in the height of the airfoil above the orifice does not change the pressure distribution to any marked extent except in those cases where the flow is unstable.

Table IV shows the good agreement between results obtained with the airfoil in its normal position and those obtained with the airfoil reversed and turned through an equal angle in the opposite direction. The differences are so small that they can not be readily shown on the scale used in Figure 15.

TABLE IV

AIRFOIL 3.—$V/c=0.5$. RATIO OF PRESSURES TO VELOCITY PRESSURE, $\frac{1}{2}\rho V^2$

Angle	Station 2		Station 6	
	Normal	Reversed	Normal	Reversed
−20°	0. 895	0. 904	−0. 428	−0. 421
−16°	. 794	. 806	−. 481	−. 479
−12°	. 664	. 676	−. 514	−. 517
−8°	. 514	. 522	−. 525	−. 524
−4°	. 353	. 362	−. 510	−. 520
−0°	. 179	. 188	−. 516	−. 520
4°	−. 059	−. 034	−. 489	−. 500
8°	−. 363	−. 339	−. 469	−. 475
12°	−. 721	−. 698	−. 440	−. 449
16°	−1. 107	−1. 088	−. 379	−. 389
20°	−1. 502	−1. 508	−. 272	−. 278
24°	−. 673	−. 681	−. 464	−. 452

A few measurements were made with a smaller orifice, 1.2 inches in diameter. As would be expected, a large effect was found because of the decrease in aspect ratio. The most striking feature of the results in the case of the smaller air stream was the marked drop in the values of the pressure decrease on the top surface. The pressures on the lower surface were not affected as much but the relations could not be expressed in any simple way.

ACCURACY

Pressure distribution.—The precision of the pressure measurements was satisfactory as illustrated by the results in Table IV, the differences occurring between the normal and reversed positions being typical of differences between repeat measurements. The operating conditions were very steady and required only occasional slight adjustments of the pressure. On the average the curves could certainly be repeated to within 1 per cent of the pipe pressure or one-twentieth of a degree where the change with angle was very great.

The application of the results to other conditions requires a consideration of other factors, the most important of which is the effect of aspect ratio. This effect is a very large one, and experimental data are still lacking to make quantitative estimates. The information available, so far as the total forces are concerned, will be summarized in the section on "Discussion and Comparison with Earlier Work." No method is as yet known for computing the effect of aspect ratio on pressure distribution, even at ordinary wind-tunnel speeds and for larger aspect ratios.

Integration of pressures.—A discussion of the precision and accuracy of the lift and drag coefficients derived from pressure measurements introduces several new considerations. It has been pointed out that the values would not be expected to agree with the forces obtained by direct measurement because of the absence of the skin friction in the pressure integration. This effect would be most pronounced in the drag coefficients which would accordingly be somewhat too low. In addition to this, it must be remembered that the pressure distribution was taken at the mid-section so that the results of the integration do not apply to an airfoil spanning the stream but to a single section only. These two factors should be studied by making force measurements on the same airfoils, and it is hoped that this can be done at a later date.

There still remains a final consideration, namely, as to the accuracy with which the resultant action of the pressure distribution has been computed from the pressures at 13 stations. It is, of course, impossible, strictly speaking, to estimate this accuracy without measuring the pressure at a very large number of stations, since we have no *a priori* knowledge of the form of the pressure-distribution curves. We can therefore only express an opinion as to the probable accuracy. To obtain a reasonable basis for this opinion we have followed the older method of drawing in curves connecting the points in a reasonable way for a number of cases, and have compared the values of the coefficients obtained by the use of a planimeter with those obtained by the numerical method. Table V shows typical results. The average difference without regard to sign is 0.01, which may be taken as a measure of the precision of the normal force coefficients.

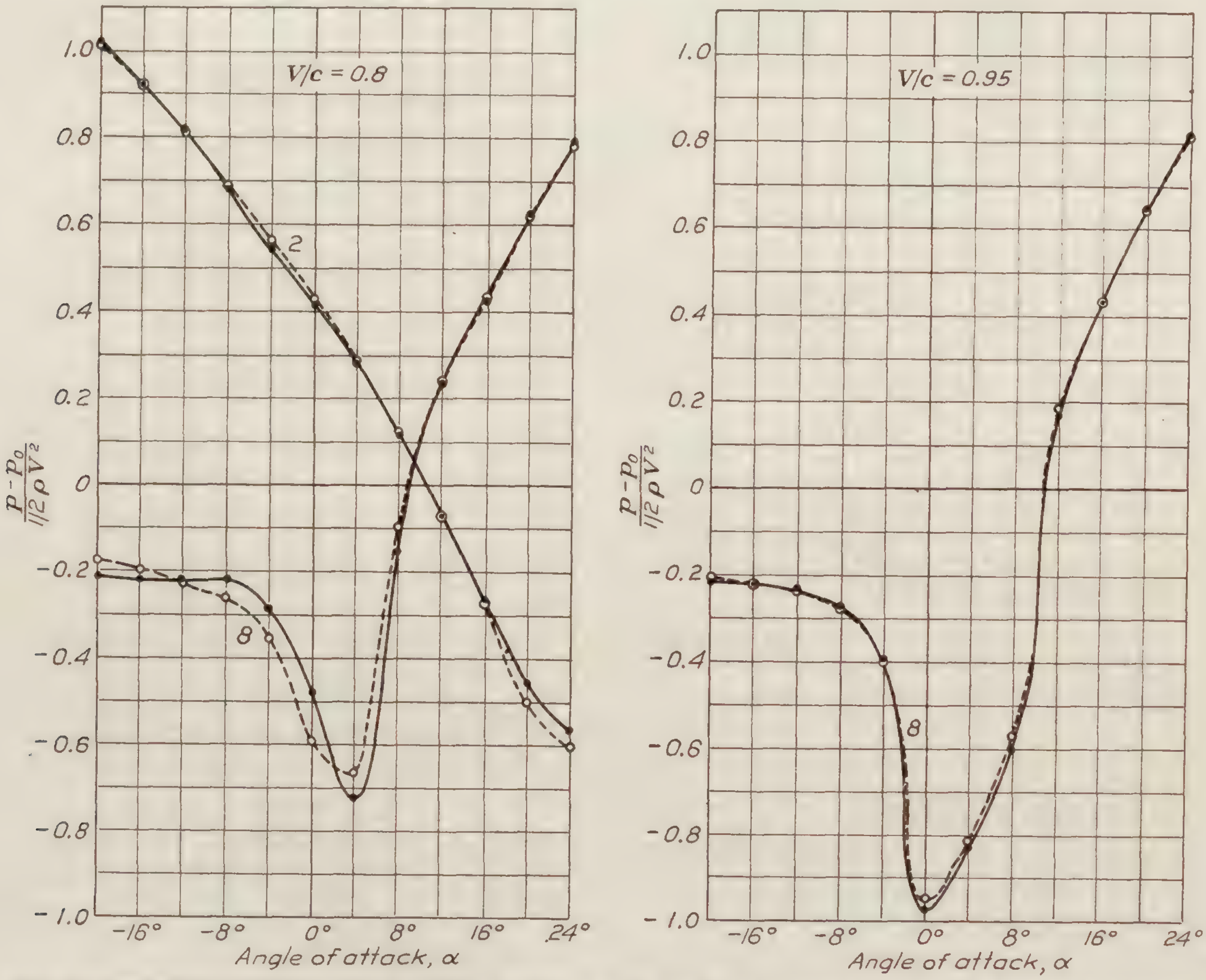


FIG. 15.—Comparison of measurements on airfoil 3 at 2 inches (solid curve) and 4 inches (dotted curve) above the plane of the orifice mouth. Numbers on curves denote stations

The tangential force coefficients are subject to a somewhat greater error because of the absence of stations near the leading and trailing edges. It is estimated that the values given are within 0.03 of the values that would have been obtained if it had been possible to use a larger number of stations. The comparative values are probably correct within 0.01 to 0.02 as judged by the smoothness of the results. From this it follows that the drag coefficients are correct within about the same limits.

The moment coefficients were computed by an approximate method described in the section on integration of pressures. The exact method was used for a few cases and found to give moment coefficient values differing by 0.007 from the approximate values, and center of pressure positions (in the flatter portions of the curve) differing by 0.02. It was not believed profitable to carry through the exact computations in all cases because the time required would have been very great and the chief interest is in relative rather than absolute values.

TABLE V

COMPARISON OF NORMAL FORCE COEFFICIENTS BY GRAPHICAL AND NUMERICAL METHODS

Angle	Airfoil 6, $V/c=0.5$		Airfoil 6, $V/c=1.08$	
	Graphical method	Numerical method	Graphical method	Numerical method
−20°	0.060	0.064	−0.218	−0.210
−16°	.145	.153	−.177	−.168
−12°	.232	.238	−.129	−.132
−8°	.275	.289	−.146	−.137
−4°	.280	.274	−.276	−.278
0°	.367	.371	−.150 to −.191	−.133 to −.171
4°	.482	.476	−.050	−.025
8°	.611	.595	.116	.125
12°	.688	.680	.221	.221
16°	.803	.811	.358	.360
20°	.499	.524	.442	.455
24°	.558	.552	.516	.528

OBSERVATIONS OF FLOW NEAR THE AIRFOILS

A description was given in Report No. 207 of the National Advisory Committee for Aeronautics of the behavoir of an oil film on the surface of an airfoil at high speeds. Some additional observations were made at Edgewood and Figures 16 and 17 illustrate the type of pattern formed. The technique of observing flow near a surface by oil films has been developed at McCook Field and elsewhere. The photograph in Figure 16 shows a film of oil and lampblack on the upper surface of airfoil 1 at 0° to the wind at a speed of 1.08 times the speed of sound. Figure 17 shows airfoil 6 under the same conditions. The flow over the greater part of the upper surface is in a direction opposite to the general direction of the stream and the air moves off in the familiar tip eddies whose traces are shown at the boundary of the air stream. It appears that the region of low pressure is broken down by a flow about the trailing edge from the lower surface and that there is a separation of the main stream from the upper surface.

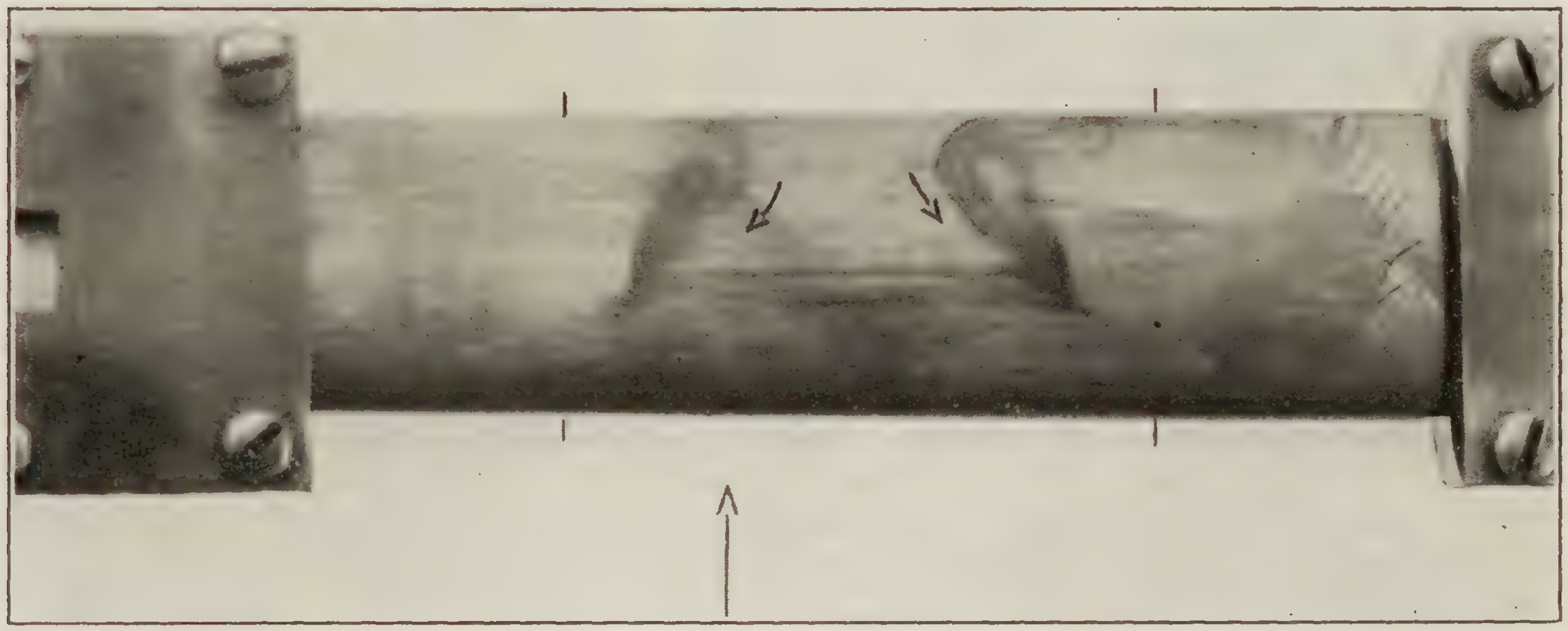


FIG. 16.—Oil flow pattern on the upper surface of airfoil 1 at 0° angle of attack, $V/c=1.08$. The flow of the air stream is toward the top of the page. Note the separation from the surface shown by the ridge of stationary oil at about 0.43 the chord length from the leading edge. The diameter of the orifice is twice the chord length of the airfoil

Time was not available to study this phenomenon in detail at Edgewood, but further observations of a similar qualitative nature were made in a 1.2-inch jet at the Bureau of Standards at a speed of 0.65 times the speed of sound. It appears that flow around the trailing edge does not occur in all cases, but that there may be a region of reverse flow and eddy formation over a limited area on the upper surface. In the case of the thin airfoils the disturbance begins as the angle to the wind is increased, in the region just behind the maximum ordinate, whereas with the thickest airfoil of 0.20 camber ratio it begins at the trailing edge. With the airfoil of 0.18 camber ratio the disturbance begins nearly simultaneously at both places.

Flow of oil mixtures of this type depends on gravity, viscosity, surface tension, adhesion, and other factors and the question was raised as to whether the oil flow corresponded to the air flow or merely to differences in pressure. An attempt was made to answer this by feeding threads through the tubing inserted in the airfoil so as to project from the airfoil through the pressure hole. (The threads were readily drawn through by a suction pump.) The threads indicated the same direction of flow as the oil on the surface. As a further check, a small exploring tube with projecting thread was constructed to explore the regions at greater distances from the airfoil. It was found that the presence of the exploring tube changed the oil flow to some extent. Nevertheless it appeared that the layer of reverse flow is extremely thin at its initial appearance but becomes thicker as the angle is increased until it is a millimeter or more in thickness.

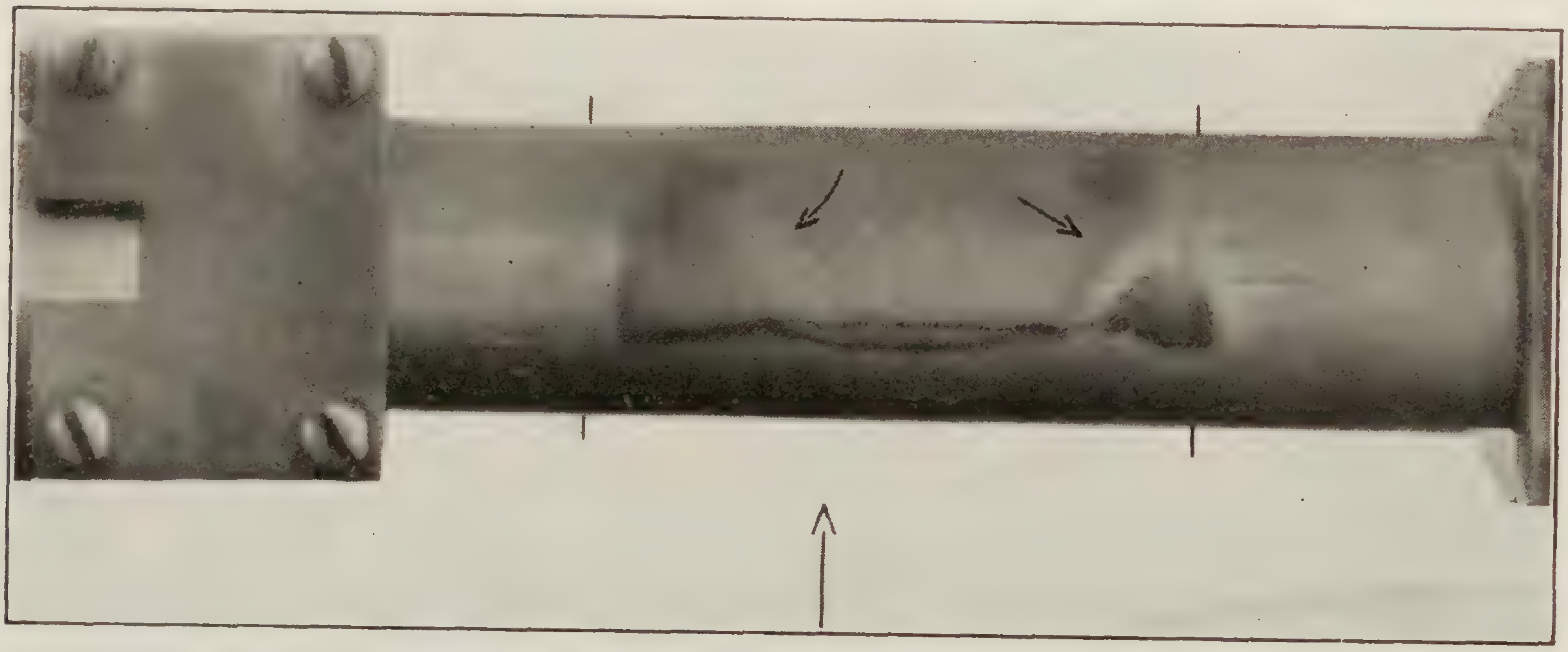


FIG. 17.—Oil flow pattern on the upper surface of airfoil 6 at 0° angle of attack, $V/c=1.08$. The flow of the air stream is toward the top of the page. Note the separation from the surface shown by the ridge of stationary oil at about 0.29 the chord length from the leading edge. The diameter of the orifice is twice the chord length of the airfoil

A change in flow thus begins in a fairly sudden manner in the boundary layer on the upper surface immediately behind the maximum ordinate for thin airfoils at the lower speeds, and at the trailing edge for thick airfoils at the lower speeds. At the lower speeds the change takes place at comparatively large angles and is analagous to the well known burble point. At the higher speeds the change takes place at small angles and is accompanied by a rapid decrease in lift coefficient and increase in drag coefficient.

At $V/c=1.08$ standing compressional waves (bow waves) were observed at a distance of about 0.5 inch in front of the leading edges of the airfoils.

DISCUSSION AND COMPARISON WITH EARLIER WORK

A careful inspection of the pressure distribution curves, Figures 4 to 9, shows the existence of regions characteristic of flow of the type described in which there is a separation from the surface. For example in Figure 6 for airfoil 3 the distribution over the upper surface for a speed of $0.5c$ at 24°, shows a sharply defined peak followed by a region of nearly constant decrease in pressure such as is found in the case of a cylinder or sphere where the flow breaks away from the surface. A similar distribution may be observed at $0.65c$ at 20° and 24°, $0.8c$ at 16°, 20°, and 24°, $0.95c$ at 4°, 8°, 12°, 16°, 20°, and 24°, and $1.08c$ at all positive angles. In fact it is possible to trace a rough locus of speeds and angles at which the change takes place. The steps in speed and in angles are unfortunately so far apart that the exact position can not be plotted, but it may be seen that for thick airfoils at a given speed the break occurs at lower angles and at a given angle at lower speeds than for the thin airfoils. The location of the change in flow is facilitated by the fact that for the burbling type of flow the pressure at the trailing edge is lower than the static pressure whereas for the smooth high lift type it is higher than the static pressure.

It must be remembered that no trace of the break can be detected in the pressure distribution until the flow is changed at one of the stations at which observations were made, so that the break in the pressure distribution as given appears less sharp than it really is. It seems evident, from the visual observation of the oil flow, that the change in flow takes place suddenly, but that it is confined to a small area at first and spreads rapidly as the speed or angle is increased. The evidence of beginning in a small region near the maximum ordinate in the case of the thin airfoils is not entirely clear from the pressure distribution curves alone, although indications may be observed, especially in the case of airfoil 4. In the case of airfoil 1 between 16° and 20° the oil flow experiments show that the reverse flow begins and spreads beyond the last station for pressure measurements, so that only in exceptional cases can the origin be traced on pressure distributions taken at intervals of 4°. The spreading is even more rapid for airfoil 6.

These rapid changes of flow are reflected in the lift coefficient curves (fig. 11) with a still greater reduction in the sharpness of the break. The sudden burble points are very noticeable in most cases for speeds of 0.5*c* and 0.65*c*. For the thin airfoils there is a rapid change in the lift coefficient with speed between 0.8*c* and 0.95*c* for all the lower angles. Similar changes occur between 0.65*c* and 0.8*c* for the thick airfoils.

These curves give in a more systematic manner than was possible in Report No. 207 the variation of lift coefficient with speed at all angles from −20° to +24°. The same shift of the angle of no lift first to high negative angles and then to 0° or a small positive angle is shown in more detail. The increase in lift coefficient at large negative angles, followed by a rapid decrease as the speed is increased, is traced to negative lift coefficients. The changes between 0.5 and 1.08 times the speed of sound increase with increasing thickness, and there is every reason to believe that the same decrease may be expected for airfoils of smaller camber than 0.10 at higher speeds. The minima in all curves at high speeds and in the curves for the thicker airfoils at low speeds are associated with the large suction on the lower surface near the leading edge which develops near 0°. It is probable that this effect would not be present with a more rounded leading edge or on a doubly cambered section.

A comparison of the lift coefficient curves with those given in Report 207 will show that the Edgewood values are lower, as would be expected from the lower aspect ratios. The results can not be directly compared, since the Edgewood values apply only to the mid-section, and the form of the lift distribution curve along the span is not known for these speeds.

The rapid change in the lift coefficient in the Edgewood experiments occurred at a value of V/c about 10 per cent greater than at Lynn. The chord length used at Edgewood was one-third that used in the Lynn measurements. Therefore the Reynolds Number at which the rapid change in the lift coefficient took place at Edgewood was only about one-third that at Lynn. The change in the lift coefficient appears therefore to be much more definitely associated with V/c than with $\rho Vl/\mu$. In other words, the compressibility effect is predominant.

There are two possible explanations for the somewhat larger value of V/c at which the rapid change in the lift coefficient occurred in the Edgewood experiments. First, the Reynolds Number may still have some effect. Second, a possible aspect ratio effect. For example, photographs taken in the 1.2-inch jet indicate that the change in flow takes place at a greater angle of attack than in the 2-inch jet for airfoil 6 and at approximately the same angle for airfoil 1. Moreover at ordinary wind tunnel speeds the burble point occurs at a greater angle of attack for the smaller aspect ratio. Hence it is possible that the exact angles and speeds at which a change in flow takes place vary with the aspect ratio.

When we come to drag coefficients there is a somewhat different state of affairs. We should expect the drag coefficient computed from the pressure integration to be lower than the true drag coefficient because of skin friction. We might also expect the coefficient for a section near the center to be somewhat lower than the average for the whole section. Hence it is probable that the total drag coefficient for the whole section is greater by some unknown amount than that computed from the pressure distribution. However, the values computed from the pressure integration at Edgewood are very much higher than those obtained at Lynn at angles near 0°. We should expect the drag coefficient for the whole section to be somewhat higher than the Lynn values owing to the smaller aspect ratio, but the difference is too great to be attributed entirely to an aspect ratio effect. It seems highly probable that there is a comparatively large effect of Reynolds Number on drag coefficient even at these high speeds. We hope to obtain more definite information on this point in later tests.

The drag coefficient curves given in Report 207, Figures 16 to 21, show a rapid rise in coefficient for angles near 0°, as, for example, Figures 21 for airfoil 6. The maximum speeds reached in most cases were between 0.8 and 0.95 the speed of sound. The Edgewood tests (fig. 12) show that this rapid increase is followed by a region of nearly constant coefficient, and in fact there is some indication of this in a few observations in Report 207. In other words, the drag curves are probably somewhat similar to the well-known Gavre curve for projectiles.

The center of pressure curves (fig. 14) give a more detailed picture of the backward motion at the usual working angles. These require little discussion, since they merely reflect the more even distribution of load at the higher speeds. The behavior at negative angles corresponds to the zero lift positions, of which there are three in some cases.

The moment curves (fig. 13) show that the effect of the reduction in force coefficients is greater than the backward motion of the center of pressure, so that the moment coefficient is in general reduced by increase in speed at a constant angle.

There remains for discussion but one observed fact which is not represented in the coefficient curves. The actual value of the maximum decrease in pressure on the upper surface seems limited, the average observed maximum value for all speeds greater than 0.5 the speed of sound and for all airfoils being approximately 32 cm. of Hg. The largest single value of $p_o - p$ observed was 37 cm. Hg. or $p/p_o = 0.51$. This ratio is not far from the critical ratio for air, namely 0.53, and this observation suggests that in an air stream in which the flow obeys the law of Bernouilli the pressure can not decrease indefinitely but reaches a limit as soon as the ratio of the pressure to the static pressure at a large distance in front of the body causing the pressure change reaches the critical value of 0.53. Lower pressures may be produced in "dead air" spaces where the flow leaves the surface of the body as on the lower surface of the airfoils near the leading edge. In this case the pressure decreased to about one-fourth of the atmospheric pressure.

CONCLUSIONS

The changes in the aerodynamic characteristics of airfoils at high speeds have been studied in detail by means of pressure distribution measurements and a more extensive and more systematic series of observations has been described. The conclusions of Report No. 207 have been verified and extended to higher speeds. Observations have been made of the air flow near the surface and correlated with the force measurements. Large changes have been shown to be associated with the sudden breaking away of the flow from the upper surface.

It has been shown that the variation in lift coefficients is due very largely to a compressibility effect, although the additional effect of viscosity can apparently still be traced in the drag coefficients.

ACKNOWLEDGMENTS

The authors wish to acknowledge their indebtedness to Messrs. W. H. A. Boyd and P. S. Murphy for assistance in connection with the measurements and to Messrs. G. C. Hill and J. L. Ewin for assistance in the reduction of the observations.

OBSERVED VALUES OF $\frac{p-p_o}{q}$, AIRFOIL 1

$V/c=0.50$

Station	Angle of attack											
	−20°	−16°	−12°	−8°	−4°	0°	4°	8°	12°	16°	20°	24°
1	1.051	1.012	0.934	0.815	0.696	0.534	0.263	−0.134	−0.637	−1.235	−1.895	−0.996
2	.796	.664	.506	.332	.144	−.061	−.348	−.718	−1.174	−1.659	−2.110	−.667
3	.414	.254	.071	−.109	−.307	−.515	−.771	−1.052	−1.325	−1.546	−1.784	−.576
4	.141	.008	−.131	−.271	−.397	−.528	−.662	−.798	−.985	−1.045	−.958	−.528
5	−.089	−.175	−.252	−.316	−.371	−.423	−.469	−.497	−.464	−.472	−.445	−.528
6	−.219	−.261	−.291	−.315	−.329	−.345	−.346	−.321	−.306	−.273	−.217	−.446
7	−.269	−.265	−.236	−.223	−.226	−.195	−.149	−.114	−.086	−.044	−.000	−.233
8	−.278	−.301	−.331	−.385	−.537	−.754	−.128	.183	.383	.576	.728	.798
9	−.284	−.308	−.333	−.391	−.519	−.587	.024	.185	.323	.479	.614	.672
10	−.305	−.328	−.357	−.394	−.475	−.210	.040	.133	.230	.349	.454	.508
11	−.322	−.346	−.369	−.384	−.275	.017	.036	.088	.149	.222	.290	.335
12	−.304	−.326	−.327	−.279	−.036	.042	.051	.082	.116	.158	.206	.232
13	−.233	−.241	−.207	−.088	.080	.082	.082	.087	.094	.114	.126	.061

$V/c=0.65$

1	1.086	1.047	0.980	0.874	0.762	0.595	0.374	0.079	−0.299	−0.706	−0.847	−0.864
2	.848	.715	.566	.396	.230	.023	−.263	−.584	−.931	−1.272	−.767	−.446
3	.470	.293	.107	−.092	−.255	−.467	−.743	−1.031	−1.328	−1.358	−.548	−.397
4	.176	.018	−.131	−.280	−.391	−.529	−.699	−.857	−1.153	−1.206	−.466	−.436
5	−.086	−.195	−.277	−.344	−.376	−.432	−.502	−.395	−.408	−.453	−.478	−.441
6	−.248	−.296	−.330	−.347	−.337	−.342	−.313	−.297	−.258	−.216	−.474	−.446
7	−.263	−.275	−.263	−.261	−.203	−.152	−.126	−.087	−.049	−.025	−.291	−.298
8	−.249	−.282	−.317	−.366	−.510	−.696	−.244	.194	.369	.560	.689	.818
9	−.257	−.298	−.324	−.371	−.490	−.561	−.068	.171	.320	.473	.572	.686
10	−.275	−.313	−.348	−.385	−.455	−.244	.049	.147	.249	.357	.434	.537
11	−.289	−.328	−.355	−.370	−.270	.015	.051	.103	.159	.224	.262	.333
12	−.263	−.306	−.320	−.286	−.053	.065	.065	.094	.124	.162	.175	.230
13	−.210	−.232	−.201	−.090	.091	.104	.096	.099	.102	.096	.037	.068

$V/c=0.80$

1	1.155	1.116	1.041	0.934	0.824	0.697	0.532	0.323	0.076	−0.205	−0.474	−0.651
2	.911	.784	.645	.495	.323	.156	−.041	−.257	−.509	{−.742 {−.772	−.733 −.798 }	−.487
3	.524	.360	.177	−.012	−.205	−.390	−.599	−.792	−.968	−.873	−.516	−.423
4	.222	.076	−.090	−.268	−.451	−.618	−.789	−.912	−.942	−.596	−.412	−.346
5	−.082	−.201	−.315	−.400	−.467	−.523	−.582	−.636	−.546	−.503	−.460	−.387
6	−.261	−.330	−.379	−.393	−.383	−.327	−.294	−.243	−.295	−.364	−.404	−.392
7	−.335	−.349	−.358	−.329	−.235	−.139	−.076	−.039	−.073	−.205	−.264	−.267
8	−.220	−.247	−.282	−.342	−.481	−.729	−.479	.136	.341	.536	.701	.838
9	−.229	−.252	−.290	−.348	−.461	−.599	−.248	.160	.310	.464	.602	.738
10	−.238	−.269	−.310	−.363	−.440	−.352	.021	.138	.243	.356	.468	.574
11	−.250	−.277	−.324	−.352	−.310	−.018	.063	.094	.147	.208	.287	.376
12	−.247	−.273	−.291	−.270	−.102	.062	.071	.087	.110	.140	.190	.252
13	−.202	−.215	−.198	−.107	.060	.117	.096	.076	.055	.041	.059	.084

$V/c=0.95$

1	1.224	1.179	1.116	1.015	0.941	0.831	0.702	0.558	0.378	0.152	−0.116	−0.436
2	.993	.879	.750	.601	.470	.330	.188	.032	−.167	−.418	−.538	−.594
3	.612	.454	.291	.128	−.027	−.169	−.314	−.438	−.574	−.627	−.571	−.535
4	.279	.118	−.063	−.221	−.363	−.465	−.554	−.664	−.536	−.468	−.348	−.276
5	−.068	−.205	−.338	−.413	−.524	−.631	−.570	−.487	−.372	−.375	−.362	−.297
6	−.277	−.366	−.441	−.518	−.607	−.581	−.423	−.376	−.387	−.429	−.388	−.305
7	−.403	−.356	−.378	−.392	−.192	−.161	−.202	−.251	−.314	−.287	−.276	−.216
8	−.224	−.244	−.254	−.258	−.575	−.895	−.651	−.058	.345	.541	.726	.879
9	−.238	−.245	−.272	−.305	−.417	−.759	−.504	.138	.314	.477	.632	.766
10	−.250	−.266	−.295	−.333	−.398	−.530	−.123	.107	.231	.370	.491	.612
11	−.263	−.279	−.310	−.325	−.319	.044	.036	.052	.126	.214	.304	.404
12	−.253	−.259	−.279	−.280	−.215	.075	.016	.037	.080	.132	.203	.279
13	−.219	−.219	−.219	−.173	−.070	.026	−.024	−.026	−.012	.010	.041	.090

$V/c=1.08$

1	1.268	1.227	1.169	1.089	0.991	0.901	0.810	0.678	0.523	0.333	0.102	−0.175
2	1.028	.925	.819	709	.583	.454	.323	.193	.029	−.197	−.362	−.433
3	.676	.539	.395	.258	.133	−.001	−.131	−.242	−.388	−.464	−.506	−.508
4	.372	.233	.086	−.056	−.182	−.311	−.431	−.538	−.554	−.449	−.290	−.276
5	.003	−.115	−.233	−.355	−.464	−.487	−.440	−.346	−.317	−.313	−.318	−.298
6	−.233	−.334	−.433	−.454	−.379	−.331	−.302	−.313	−.322	−.322	−.325	−.290
7	−.325	−.363	−.371	−.257	−.209	−.242	−.278	−.282	−.297	−.326	−.286	−.219
8	−.233	−.257	−.268	−.378	−.784	−.630	−.441	−.170	.403	.588	.764	.909
9	−.238	−.260	−.276	−.439	−.708	−.539	−.334	.058	.363	.532	.678	.814
10	−.246	−.274	−.297	−.413	−.575	−.393	−.338	.101	.264	.408	.532	.650
11	−.260	−.276	−.289	−.350	−.570	−.416	−.241	−.034	.102	.212	.311	.417
12	−.242	−.257	−.262	−.286	−.113	−.030	.041	.052	.012	.091	.164	.257
13	−.199	−.220	−.230	−.184	.004	.125	.115	.017	−.001	.001	.033	.082

OBSERVED VALUES OF $\frac{p-p_o}{q}$, AIRFOIL 2

$V/c=0.50$

Station	Angle of attack											
	-20°	-16°	-12°	-8°	-4°	0°	4°	8°	12°	16°	20°	24°
1	1.069	1.056	1.014	0.947	0.857	0.748	0.558	0.275	-0.106	-0.528	-1.025	-0.588
2	.858	.736	.589	.402	.245	.002	-.264	-.539	-1.025	-1.487	-1.910	-.799
3	.426	.254	.054	-.151	-.344	-.554	-.806	-1.099	-1.412	-1.704	-1.884	-.356
4	.089	-.049	-.208	-.358	-.499	-.629	-.755	-.881	-1.056	-1.380	-1.305	-.360
5	-.140	-.233	-.308	-.380	-.438	-.483	-.534	-.573	-.489	-.510	-.472	-.407
6	-.311	-.359	-.394	-.416	-.431	-.434	-.429	-.395	-.373	-.325	-.249	-.473
7	-.328	-.320	-.320	-.306	-.310	-.234	-.179	-.140	-.099	-.034	.012	-.352
8	-.276	-.285	-.310	-.344	-.444	-.679	-.453	.189	.341	.553	.717	.776
9	-.281	-.297	-.322	-.357	-.462	-.620	.006	.140	.284	.447	.586	.647
10	-.310	-.334	-.359	-.378	-.447	-.330	.033	.124	.224	.339	.449	.498
11	-.326	-.342	-.364	-.374	-.318	.017	.037	.086	.143	.209	.283	.318
12	-.308	-.324	-.327	-.294	-.127	.051	.049	.075	.114	.155	.200	.209
13	-.246	-.249	-.219	-.118	.071	.109	.099	.100	.114	.122	.132	.064

$V/c=0.65$

1	1.117	1.108	1.057	0.989	0.912	0.807	0.662	0.453	0.195	-0.121	-0.279	-0.509
2	.899	.777	.634	.460	.303	.125	-.113	-.393	-.666	-.981	-.712	-.663
3	.467	.285	.095	-.105	-.291	-.485	-.755	-1.078	-1.388	-1.447	-.396	-.385
4	.122	-.041	-.200	-.365	-.482	-.617	-.792	-.948	-1.214	-1.275	-.394	-.362
5	-.135	-.246	-.353	-.403	-.432	-.488	-.569	-.423	-.430	-.472	-.416	-.453
6	-.345	-.414	-.446	-.461	-.437	-.417	-.389	-.363	-.304	-.248	-.485	-.472
7	-.342	-.379	-.374	-.370	-.261	-.183	-.147	-.099	-.049	-.029	-.360	-.348
8	-.251	-.263	-.290	-.320	-.428	-.623	-.546	.076	.343	.529	.671	807
9	-.251	-.275	-.312	-.355	-.438	-.579	- 120	.128	.278	.437	.539	.671
10	-.278	-.301	-.324	-.352	-.423	-.396	.012	.130	.235	.344	.419	.534
11	-.282	-.318	-.342	-.368	-.319	.002	.055	.102	.155	.219	.261	.342
12	-.267	-.297	-.308	-.294	-.127	.069	.066	.085	.120	.157	.175	.231
13	-.226	-.238	-.213	-.131	.064	.127	.112	.107	.109	.102	.044	.076

$V/c=0.80$

1	1.162	1.148	1.107	1.055	0.981	0.910	0.796	0.651	0.468	0.254	0.022	-0.246
2	.960	.852	.717	.574	.421	.274	.103	-.076	-.294	-.479	-.566	-.579
3	.526	.360	.164	-.018	-.209	-.392	-.612	-.840	-.988	-.729	-.397	-.401
4	.171	.002	-.181	-.337	-.516	-.694	-.835	-.950	-.884	-.583	-.376	-.315
5	-.129	-.246	-.355	-.444	-.510	-.617	-.742	-.758	-.546	-.493	-.405	-.352
6	-.394	-.468	-.517	-.530	-.517	-.444	-.386	-.297	-.323	-.383	-.439	-.407
7	- 441	-.470	-.462	-.390	-.285	-.159	-.073	-.050	-.119	-.295	-.303	-.288
8	-.200	-.226	-.257	-.308	-.424	-.654	-.643	-.037	.338	.522	.701	.838
9	-.206	-.230	-.270	-.321	-.435	-.606	-.287	.136	.271	.429	.583	.715
10	-.229	-.255	-.294	-.335	-.408	-.420	-.089	.124	.222	.341	.454	.568
11	-.234	-.269	-.310	-.338	-.336	-.048	.063	.087	.159	.207	.286	.370
12	-.227	-.256	-.276	-.268	-.163	.053	.069	.071	.094	.132	.184	.248
13	-.191	-.214	-.195	-.135	.030	.128	.102	.067	.042	.041	.053	.088

$V/c=0.95$

1	1.236	1.233	1.194	1.133	1.074	1.003	0.925	0.818	0.676	0.489	0.272	0.035
2	1.050	.938	.824	.686	.552	.434	.314	.179	.011	-.194	-.416	-.445
3	.610	.456	.290	.127	-.041	-.193	-.357	-.511	-.575	-.371	-.284	-.256
4	.254	.106	-.040	-.206	-.359	-.493	-.641	-.683	-.632	-.495	-.399	-.335
5	-.066	-.204	-.367	-.516	-.620	-.591	-.534	-.432	-.389	-.389	-.342	-.287
6	-.382	-.445	-.518	-.576	-.547	-.439	-.363	-.377	-.384	-.396	-.383	-.309
7	-.412	-.449	-.458	-.371	-.241	-.192	-.244	-.304	-.345	-.350	-.330	-.264
8	-.223	-.244	-.257	-.274	-.414	-1.030	-.864	-.496	.299	.531	.711	.877
9	-.223	-.243	-.260	-.296	-.445	-.783	-.566	.082	.274	.440	.601	.746
10	-.240	-.266	-.282	-.304	-.389	-.618	-.316	.118	.220	.351	.475	.610
11	-.258	-.281	-.305	-.327	-.215	.015	.068	.056	.121	.208	.300	.393
12	-.240	-.270	-.272	-.279	-.259	.077	.020	.027	.065	.119	.183	.258
13	-.205	-.221	-.223	-.204	-.119	.019	-.010	-.014	.001	.026	.056	.103

$V/c=1.08$

1	1.286	1.271	1.245	1.205	1.148	1.075	0.995	0.906	0.792	0.637	0.456	0.240
2	1.102	1.020	.906	.784	.670	.559	.452	.336	.204	.021	-.183	-.339
3	.698	.564	.427	.278	.138	.003	-.163	-.286	-.389	-.524	-.602	-.229
4	.362	.233	.095	-.053	-.180	-.307	-.436	-.434	-.352	-.433	-.358	-.248
5	-.007	-.144	-.272	-.384	-.423	-.429	-.444	-.360	-.351	-.330	-.368	-.274
6	-.326	-.419	-.427	-.355	-.299	-.298	-.297	-.314	-.331	-.328	-.306	-.281
7	-.328	-.346	-.317	-.237	-.228	-.250	-.281	-.305	-.330	-.325	-.282	-.260
8	-.230	-.257	-.277	-.387	-.866	-.756	-.602	-.379	.329	.568	.741	.894
9	-.234	-.258	-.282	-.400	-.721	-.563	-.366	-.079	.311	.477	.632	.774
10	-.264	-.285	-.303	-.403	-.626	-.453	-.254	.027	.232	.379	.507	.628
11	-.261	-.277	-.298	-.378	-.583	-.432	-.254	-.068	.090	.205	.303	.411
12	-.245	-.260	-.268	-.295	-.154	-.102	-.140	.009	-.007	.070	.155	.248
13	-.200	-.217	-.221	-.208	-.037	.079	.152	.062	-.011	-.003	.033	.085

OBSERVED VALUES OF $\frac{p-p_o}{q}$, AIRFOIL 3

V/c=0.50

Station	Angle of attack											
	−20°	−16°	−12°	−8°	−4°	0°	4°	8°	12°	16°	20°	24°
1	1.057	1.054	1.022	0.963	0.891	0.801	0.645	0.411	0.103	−0.292	−0.707	−0.461
2	.895	.794	.664	.514	.353	.179	−.059	−.363	−.721	−1.107	−1.502	−.673
3	.405	.227	.033	−.168	−.369	−.611	−.891	−1.195	−1.510	−1.756	−1.873	−.325
4	.067	−.097	−.250	−.408	−.554	−.693	−.838	−.990	−1.172	−1.420	−1.630	−.272
5	−.226	−.320	−.408	−.468	−.527	−.579	−.640	−.715	−.566	−.571	−.532	−.385
6	−.428	−.481	−.514	−.525	−.510	−.516	−.489	−.469	−.440	−.379	−.272	−.464
7	−.321	−.347	−.385	−.394	−.308	−.163	−.142	−.102	−.050	.003	.028	−.322
8	−.250	−.258	−.274	−.302	−.396	−.630	−.562	.001	.250	.470	.644	.712
9	−.276	−.289	−.303	−.334	−.441	−.651	−.123	.138	.263	.424	.571	.636
10	−.291	−.307	−.323	−.347	−.431	−.378	.016	.104	.204	.316	.423	.482
11	−.319	−.334	−.344	−.365	−.344	−.001	.038	.088	.140	.207	.279	.317
12	−.310	−.319	−.321	−.297	−.155	.059	.056	.081	.114	.154	.199	.204
13	−.240	−.245	−.213	−.127	.052	.117	.106	.106	.113	.123	.127	.050

V/c=0.65

1	1.102	1.095	1.064	1.009	0.947	0.864	0.744	0.567	0.330	0.064	−0.094	−0.353
2	.935	.839	.717	.574	.434	.283	.085	−.140	−.414	−.665	−.641	−.654
3	.449	.275	.076	−.124	−.324	−.525	−.802	−1.062	−1.356	−.978	−.441	−.410
4	.094	−.071	−.240	−.396	−.537	−.681	−.867	−1.071	−1.277	−.936	−.502	−.384
5	−.226	−.341	−.434	−.502	−.550	−.614	−.691	−.598	−.510	−.504	−.457	−.427
6	−.470	−.539	−.569	−.561	−.528	−.474	−.461	−.422	−.349	−.377	−.482	−.467
7	−.393	−.426	−.447	−.369	−.217	−.134	−.095	−.041	−.004	−.275	−.341	−.330
8	−.227	−.249	−.256	−.287	−.386	−.550	−.599	−.003	.247	.455	.596	.756
9	−.247	−.270	−.286	−.322	−.432	−.581	−.317	.120	.287	.432	.542	.669
10	−.261	−.290	−.299	−.335	−.422	−.423	−.014	.126	.222	.325	.411	.521
11	−.280	−.308	−.329	−.357	−.333	−.032	.063	.097	.164	.219	.260	.337
12	−.259	−.289	−.301	−.286	−.138	.081	.080	.101	.134	.163	.180	.235
13	−.217	−.227	−.208	−.137	.054	.137	.120	.113	.113	.111	.058	.077

V/c=0.80

1	1.160	1.150	1.127	1.087	1.031	0.955	0.859	0.735	0.568	0.366	0.133	−0.123
2	1.012	.923	.814	.687	.562	.431	.286	.123	−.071	−.273	−.501	−.602
3	.540	.372	.186	−.007	−.193	−.369	−.562	−.756	−.772	−.601	−.398	−.335
4	.174	.011	−.165	−.347	−.542	−.768	−.956	−.974	−.773	−.514	−.349	−.311
5	−.214	−.315	−.431	−.560	−.686	−.836	−.860	−.683	−.497	−.445	−.405	−.373
6	−.503	−.508	−.546	−.591	−.554	−.501	−.390	−.370	−.439	−.434	−.434	−.404
7	−.494	−.537	−.506	−.365	−.215	−.069	−.041	−.117	−.240	−.298	−.330	−.305
8	−.188	−.209	−.240	−.276	−.372	−.583	−.672	−.110	.215	.418	.613	.776
9	−.200	−.209	−.246	−.287	−.401	−.594	−.435	.044	.256	.421	.574	.715
10	−.214	−.241	−.273	−.314	−.393	−.435	−.106	.102	.206	.317	.432	.549
11	−.233	−.269	−.298	−.333	−.336	−.119	.051	.075	.135	.200	.278	.369
12	−.232	−.254	−.263	−.250	−.152	.036	.069	.066	.091	.126	.183	.248
13	−.193	−.207	−.201	−.147	.006	.122	.084	.042	.002	.016	.042	.078

V/c=0.95

1	1.236	1.232	1.204	1.162	1.112	1.052	0.986	0.881	0.758	0.586	0.377	0.153
2	1.091	1.009	.918	.802	.699	.581	.439	.340	.192	−.002	−.241	−.412
3	.638	.480	.322	.161	.006	−.134	−.287	−.432	−.522	−.502	−.296	−.258
4	.276	.127	−.015	−.225	−.412	−.534	−.625	−.591	−.398	−.332	−.301	−.279
5	−.199	−.367	−.498	−.581	−.642	−.552	−.478	−.366	−.345	−.347	−.332	−.285
6	−.436	−.546	−.556	−.540	−.485	−.335	−.365	−.366	−.391	−.365	−.351	−.307
7	−.462	−.475	−.402	−.330	−.241	−.250	−.297	−.334	−.355	−.332	−.306	−.258
8	−.208	−.225	−.240	− 281	−.401	−.949	−.818	−.571	.189	.432	.644	.813
9	−.228	−.249	−.265	−.304	−.443	−.880	−.654	−.070	.273	.433	.600	.756
10	−.240	−.258	−.276	−.317	−.407	−.629	−.317	.097	.197	.333	.467	.594
11	−.259	−.280	−.297	−.324	−.368	−.017	.086	.063	.124	.207	.300	.399
12	−.251	−.271	−.292	−.301	−.282	.100	.061	.049	.081	.121	.185	.261
13	−.215	−.226	−.226	−.219	−.146	.009	−.010	.006	.010	.035	.066	.108

V/c=1.08

1	1.282	1.276	1.256	1,224	1.179	1.112	1.039	0.954	0.853	0.710	0.535	0.338
2	1.146	1.072	.983	.886	.785	.682	.570	.454	.332	.174	−.040	−.274
3	.722	.584	.441	.297	.164	.026	−.113	−.229	−.342	−.407	−.405	−.223
4	.377	.258	.106	−.069	−.207	−.330	−.434	−.432	−.327	−.287	−.258	−.236
5	−.099	−.229	−.347	−.442	−.413	−.367	−.366	−.338	−.305	−.299	−.275	−.254
6	−.363	−.425	−.399	−.373	−.285	−.290	−.313	−.326	−.325	−.309	−.301	−.293
7	−.338	−.326	−.305	−.269	−.229	−.261	−.302	−.319	−.323	−.323	−.275	−.236
8	−.221	−.248	−.265	−.328	−.790	−.687	−.570	−.381	.098	.477	.681	.848
9	−.236	−.260	−.281	−.343	−.774	−.625	−.440	−.181	.330	.481	.640	.786
10	−.249	−.275	−.299	−.359	−.644	−.469	−.273	.011	.209	.360	.493	.618
11	−.266	−.282	−.297	−.340	−.612	−.464	−.294	−.111	.073	.193	.309	.408
12	−.256	−.272	−.289	−.338	−.176	−.121	−.081	.042	−.007	.064	.151	.249
13	−.203	−.230	−.245	−.238	−.038	.065	.158	.089	.033	.028	.062	.107

OBSERVED VALUES OF $\frac{p-p_o}{q}$, AIRFOIL 4

V/*c*=0.50

Station	Angle of attack											
	−20°	−16°	−12°	−8°	−4°	0°	4°	8°	12°	16°	20°	24°
1	1.055	1.047	1.017	0.970	0.901	0.825	0.696	0.502	0.253	−0.048	−0.001	−0.209
2	.857	.733	.582	.521	.224	.015	−.247	−.571	−.952	−1.359	−.776	−.739
3	.397	.209	.002	−.208	−.429	−.650	−.901	−1.203	−1.511	−1.819	−.414	−.312
4	−.035	−.208	−.380	−.546	−.695	−.846	−.993	−1.135	−1.322	−1.513	−.381	−.324
5	−.287	−.385	−.482	−.548	−.602	−.649	−.713	−.544	−.562	−.554	−.413	−.369
6	−.675	−.717	−.736	−.721	−.668	−.638	−.660	−.675	−.588	−.468	−.487	−.453
7	−.410	−.444	−.474	−.478	−.328	−.152	−.123	−.062	−.014	.020	−.352	−.329
8	−.255	−.266	−.270	−.300	−.382	−.584	−.708	−.266	.219	.468	.572	.734
9	−.269	−.280	−.291	−.316	−.397	−.613	−.264	.104	.244	.408	.509	.612
10	−.283	−.295	−.305	−.334	−.404	−.481	.011	.091	.191	.301	.364	.471
11	−.312	−.329	−.332	−.350	−.362	−.085	.042	.079	.136	.198	.236	.306
12	−.301	−.314	−.315	−.303	−.208	.072	.060	.080	.106	.148	.138	.197
13	−.234	−.237	−.208	−.133	.047	.139	.107	.099	.101	.105	.003	.037

V/*c*=0.65

1	1.096	1.082	1.061	1.019	0.962	0.891	0.792	0.651	0.449	0.313	0.109	−0.095
2	.895	.770	.624	.475	.307	.112	−.120	−.365	−.662	−.718	−.793	−.797
3	.431	.257	.062	−.130	−.334	−.517	−.737	−1.005	−1.296	−1.184	−.436	−.373
4	−.015	−.200	−.381	−.544	−.701	−.851	−1.090	−1.315	−1.346	−.419	−.363	−.361
5	−.301	−.407	−.502	−.560	−.603	−.653	−.555	−.494	−.544	−.402	−.407	−.416
6	−.752	−.812	−.823	−.769	−.706	−.661	−.662	−.555	−.371	−.474	−.478	−.463
7	−.486	−.524	−.548	−.444	−.243	−.113	−.045	−.006	−.023	−.361	−.357	−.345
8	−.227	−.243	−.255	−.280	−.362	−.519	−.639	−.319	.194	.400	.611	.777
9	−.235	−.252	−.261	−.305	−.377	−.539	−.458	.015	.253	.401	.534	.675
10	−.253	−.274	−.286	−.315	−.386	−.460	−.100	.102	.204	.278	.390	.510
11	−.273	−.299	−.310	−.332	−.351	−.162	.059	.095	.151	.192	.255	.332
12	−.261	−.288	−.294	−.286	−.198	.067	.079	.089	.117	.130	.167	.221
13	−.212	−.224	−.208	−.139	.037	.149	.116	.096	.081	.009	.032	.055

V/*c*=0.80

1	1.160	1.153	1.133	1.099	1.055	0.986	0.912	0.808	0.674	0.509	0.318	0.109
2	.964	.851	.721	.577	.425	.280	.118	−.060	−.253	−.432	−.607	−.683
3	.534	.371	.194	.012	−.164	−.321	−.491	−.666	−.713	−.617	−.567	−.826
4	.091	−.068	−.250	−.466	−.688	−.908	−1.012	−.852	−.477	−.397	−.339	−.312
5	−.248	−.377	−.506	−.662	−.768	−.881	−.742	−.551	−.434	−.411	−.373	−.339
6	−.821	−.899	−.910	−.849	−.800	−.622	−.419	−.412	−.448	−.449	−.428	−.398
7	−.501	−.537	−.488	−.404	−.202	−.064	−.091	−.226	−.316	−.344	−.330	−.312
8	−.201	−.216	−.236	−.271	−.370	−.617	−.774	−.582	−.034	.384	.618	.792
9	−.204	−.219	−.247	−.276	−.362	−.563	−.592	−.178	.221	.387	.543	.691
10	−.179	−.214	−.247	−.280	−.385	−.463	−.230	.073	.176	.289	.408	.534
11	−.194	−.234	−.264	−.291	−.326	−.154 −.236	.022	.068	.137	.193	.266	.356
12	−.232	−.252	−.277	−.276	−.232	.002	.060	.062	.080	.122	.174	.243
13	−.186	−.206	−.205	−.151	−.014	.109	.050	.013	−.019	−.001	.029	.069

V/*c*=0.95

1	1.233	1.231	1.218	1.177	1,138	1.078	1.009	0.926	0.823	0.681	0.520	0.330
2	1.046	.947	.837	.711	.577	.444	.311	.169	.016	−.170	−.366	−.535
3	.640	.494	.345	.195	.052	−.081	−.235	−.381	−.508	−.578	−.340	−.275
4	.187	.017	−.173	−.367	−.529	−.643	−.627	−.435	−.343	−.309	−.262	−.260
5	−.178	−.347	−.493	−.580	−.620	−.535	−.406	−.353	−.338	−.323	−.289	−.261
6	−.664	−.696	−.632	−.526	−.396	−.326	−.341	−.371	−.387	−.361	−.348	−.302
7	−.532	−.480	−.428	−.383	−.266	−.280	−.314	−.346	−.360	−.320	−.306	−.265
8	−.224	−.245	−.263	−.299	−.416	−1.077	−.948	−.764	−.194	.376	.630	.829
9	−.219	−.249	−.266	−.301	−.409	−.947	−.733	−.355	.204	.394	.571	.734
10	−.238	−.263	−.285	−.327	−.428	−.688	−.432	.093	.175	.309	.447	.577
11	−.254	−.279	−.301	−.326	−.387	−.066	.080	.062	.112	.193	.294	.392
12	−.249	−.270	−.287	−.309	−.324	.067	.080	.055	.082	.129	.183	.267
13	−.205	−.226	−.239	−.234	−.177	−.021	−.022	−.024	−.006	.016	.054	.098

V/*c*=1.08

1	1.290	1.284	1.266	1.236	1.196	1.140	1.072	0.998	0.912	0.794	0.664	0.486
2	1.115	1.020	.912	.791	.673	.571	.432	.302	.175	.015	−.163	−.318
3	.726	.603	.469	.343	.253	.091	−.053	−.182	−.295	−.402	−.350	−.199
4	.289	.133	−.037	−.188	−.327	−.429	−.454	−.359	−.291	−.273	−.265	−.224
5	−.111	−.241	−.354	−.417	−.372	−.383	−.350	−.322	−.307	−.297	−.269	−.258
6	−.518	−.444	−.348	−.336	−.261	−.274	−.301	−.314	−.311	−.298	−.280	−.260
7	−.310	−.318	−.301	−.284	−.238	−.265	−.298	−.313	−.321	−.301	−.291	−.261
8	−.230	−.253	−.277	−.327	−.917	−.815	−.686	−.520	−.220	.390	.673	.860
9	−.244	−.264	−.285	−.335	−.836	−.680	−.506	−.270	.268	.440	.604	.758
10	−.250	−.269	−.297	−.358	−.694	−.534	−.346	−.065	.182	.334	.472	.598
11	−.266	−.285	−.303	−.333	−.599	−.512	−.343	−.156	.064	.174	.286	.388
12	−.261	−.277	−.294	−.323	−.187	−.106	−.037	.106	.008	.069	.140	.241
13	−.213	−.236	−.249	−.256	−.060	.050	.146	.082	.021	.009	.034	.081

OBSERVED VALUES OF $\frac{p-p_o}{q}$, AIRFOIL 5

$V/c=0.50$

Station	Angle of attack											
	−20°	−16°	−12°	−8°	−4°	0°	4°	8°	12°	16°	20°	24°
1	1.051	1.049	1.032	0.989	0.936	0.864	0.746	0.566	0.336	0.045	−0.275	−0.141
2	.904	.809	.683	.539	.380	.208	.018	−.237	−.551	−.863	−.457	−.496
3	.400	.212	.004	−.214	−.435	−.658	−.919	−1.225	−1.565	−1.912	−2.181 −.468	−.313
4	−.067	−.258	−.444	−.628	−.797	−.965	−1.132	−1.278	−1.397	−1.534	−1.718	−.309
5	−.393	−.497	−.588	−.663	−.710	−.754	−.817	−.932	−.651	−.676	−.658	−.344
6	−.587	−.640	−.671	−.662	−.642	−.641	−.622	−.523	−.468	−.345	−.468	−.436
7	−.473	−.517	−.541	−.530	−.271	−.136	−.083	−.021	.020	.031	−.054	−.323
8	−.252	−.260	−.266	−.278	−.341	−.530	−.708	−.379	.140	.413	.603	.686
9	−.250	−.269	−.273	−.292	−.376	−.605	−.382	.119	.240	.366	.523	.598
10	−.273	−.282	−.285	−.315	−.386	−.491	−.040	.071	.173	.279	.387	.448
11	−.301	−.309	−.317	−.336	−.357	−.179	.041	.070	.125	.189	.259	.291
12	−.295	−.308	−.310	−.306	−.238	.056	.055	.062	.092	.131	.168	.170
13	−.224	−.223	−.203	−.139	.000	.151	.119	.105	.103	.103	.099	.021

$V/c=0.65$

1	1.098	1.094	1.076	1.040	1.002	0.938	0.844	0.711	0.538	0.349	0.133	−0.113
2	.954	.866	.756	.632	.501	.365	.196	−.012	−.214	−.259	−.404	−.610
3	.452	.279	.087	−.105	−.304	−.492	−.747	−1.047	−1.320	−.892	−.683	−.564
4	−.041	−.227	−.426	−.608	−.769	−.910	−1.127	−1.321	−1.345	−.407	−.350	−.318
5	−.416	−.524	−.626	−.686	−.737	−.814	−.861	−.736	−.680	−.377	−.371	−.368
6	−.653	−.712	−.734	−.722	−.705	−.601	−.507	−.432	−.307	−.466	−.445	−.435
7	−.561	−.604	−.612	−.446	−.247	−.085	−.110	.022	−.018	−.347	−.329	−.330
8	−.226	−.243	−.240	−.263	−.342	−.518	−.666	−.426	.136	.325	.547	.727
9	−.231	−.246	−.248	−.278	−.380	−.534	−.495	.059	.260	.384	.519	.665
10	−.248	−.263	−.269	−.292	−.370	−.462	−.176	.076	.182	.255	.372	.495
11	−.276	−.294	−.301	−.320	−.352	−.215	.046	.086	.138	.184	.240	.321
12	−.268	−.293	−.300	−.297	−.234	.022	.075	.074	.093	.066	.128	.195
13	−.215	−.220	−.208	−.156	−.006	.151	.125	.102	.074	−.035	−.004	.038

$V/c=0.80$

1	1.166	1.157	1.139	1.113	1.071	1.020	0.956	0.856	0.729	0.573	0.385	0.176
2	1.036	.945	.855	.743	.625	.516	.401	.268	.117	−.041	−.201	−.352
3	.564	.395	.229	.049	−.129	−.305	−.476	−.647	−.690	−.624	−.387	−.403
4	.068	−.115	−.298	−.508	−.697	−.841	−.912	−.859	−.557	−.601	−.456	−.340
5	−.323	−.448	−.643	−.803	−.901	−.897 −.786	−.688	−.516	−.428	−.399	−.376	−.339
6	−.594	−.702	−.738	−.752	−.648	−.480	−.390	−.406	−.424	−.419	−.408	−.366
7	−.564	−.606	−.571	−.468	−.212	−.127	−.200	−.280	−.344	−.358	−.324	−.298
8	−.168	−.191	−.212	−.249	−.347	−.571 −.672	−.816	−.654	−.111	.326	.574	.763
9	−.202	−.214	−.235	−.268	−.376	−.577 −.625	−.625	−.187	.249	.390	.551	.703
10	−.222	−.234	−.251	−.281	−.373	−.496	−.310	.027	.149	.270	.395	.520
11	−.235	−.250	−.288	−.310	−.353	−.289	.000	.059	.108	.183	.260	.352
12	−.190	−.219	−.243	−.252	−.230	−.034 .018	.028	.022	.039	.087	.149	.215
13	−.181	−.198	−.197	−.156	−.049	.046	.015	−.019	−.036	−.020	.018	.060

$V/c=0.95$

1	1.234	1.229	1.216	1.192	1.164	1.108	1.041	0.972	0.880	0.736	0.577	0.383
2	1.112	1.046	.963	.861	.761	.659	.561	.448	.327	.184	.025	−.177
3	.683	.538	.382	.225	.071	−.080	−.228	−.360	−.477	−.518	−.459	−.391
4	.194	.032	−.129	−.304	−.435	−.534	−.566	−.518	−.486	−.610	−.620	−.368
5	−.265	−.414	−.504	−.587	−.552	−.511	−.457	−.362	−.327	−.316	−.292	−.253
6	−.535	−.542	−.524	−.475	−.346	−.312	−.340	−.358	−.364	−.358	−.331	−.287
7	−.411	−.392	−.363	−.328	−.256	−.282	−.320	−.353	−.362	−.351	−.296	−.253
8	−.229	−.248	−.277	−.332	−.431	−1.084	−.960	−.799	−.342	.373	.592	.798
9	−.228	−.249	−.270	−.326	−.443	−.993	−.776	−.455	.220	.393	.566	.732
10	−.241	−.264	−.289	−.332	−.439	−.651	−.485	.067	.154	.286	.423	.558
11	−.267	−.286	−.308	−.340	−.411	−.122	.073	.061	.102	.180	.269	.371
12	−.264	−.279	−.297	−.332	−.362	.006	.056	.024	.039	.086	.154	.234
13	−.214	−.231	−.246	−.249	−.223	−.056	−.020	−.025	−.012	.014	.049	.086

$V/c=1.08$

1	1.284	1.282	1.270	1.241	1.200	1.162	1.098	1.027	0.944	0.826	0.688	0.515
2	1.165	1.091	1.012	.924	.837	.747	.656	.552	.448	.327	.182	.008
3	.755	.626	.490	.356	.215	.083	−.050	−.325	−.282	−.413	−.466	−.491
4	.303	.164	.013	−.130	−.246	−.351	−.404	−.415	−.325	−.295	−.264	−.228
5	−.159	−.277	−.409	−.425	−.356	−.339	−.336	−.342	−.299	−.287	−.262	−.242
6	−.348	−.319	−.332	−.293	−.254	−.270	−.302	−.321	−.315	−.303	−.290	−.269
7	−.366	−.329	−.326	−.269	−.246	−.282	−.294	−.314	−.291	−.276	−.244	−.212
8	−.233	−.254	−.274	−.298	−.885	−.821	−.704	−.558	−.352	.340	.614	.824
9	−.236	−.254	−.273	−.303	−.844	−.726	−.558	−.339	.241	.436	.598	.760
10	−.249	−.269	−.289	−.325	−.735	−.584	−.399	−.144	.156	.305	.454	.588
11	−.274	−.293	−.307	−.335	−.604	−.536	−.368	−.180	.041	.159	.270	.373
12	−.270	−.290	−.299	−.350	−.226	−.156	−.123	.017	.005	.030	.125	.220
13	−.215	−.242	−.264	−.270	−.078	.044	.143	.111	.028	.020	.048	.090

OBSERVED VALUES OF $\frac{p-p_o}{q}$, AIRFOIL 6

$V/c=0.50$

Station	Angle of attack											
	−20°	−16°	−12°	−8°	−4°	0°	4°	8°	12°	16°	20°	24°
1	1.050	1.047	1.037	1.007	0.966	0.908	0.830	0.693	0.511	0.288	0.008	0.119
2	.926	.835	.718	.588	.445	.275	.089	−.161	−.451	−.768	−1.093	−.507
3	.421	.232	.032	−.178	−.393	−.606	−.858	−1.167	−1.490	−1.824	−.634	−.265
4	−.124	−.302	−.489	−.678	−.844	−.992	−1.151	−1.301	−1.454	−1.630	−.325	−.278
5	−.473	−.576	−.667	−.738	−.788	−.830	−.889	−.988	−.727	−.736	−.611	−.332
6	−.688	−.740	−.766	−.751	−.729	−.718	−.634	−.575	−.505	−.405	−.237	−.429
7	−.552	−.600	−.628	−.571	−.276	−.143	−.072	.028	.019	−.007	−.076	−.298
8	−.239	−.246	−.237	−.248	−.317	−.471	−.680	−.491	.067	.365	.466	.657
9	−.244	−.257	−.252	−.264	−.327	−.522	−.548	.033	.227	.338	.422	.564
10	−.267	−.271	−.269	−.279	−.332	−.455	−.213	.064	.152	.259	.363	.426
11	−.292	−.296	−.296	−.316	−.349	−.232	.048	.067	.120	.179	.205	.283
12	−.281	−.285	−.285	−.293	−.231	.023	.063	.067	.096	.134	.116	.173
13	−.217	−.220	−.206	−.159	−.035	.163	.125	.106	.104	.101	.091	.022

$V/c=0.65$

1	1.106	1.102	1.095	1.071	1.035	0.986	0.919	0.820	0.691	0.582	0.415	0.230
2	.973	.902	.807	.688	.557	.419	.263	.064	−.123	−.195	−.340	−.457
3	.498	.329	.148	−.043	−.235	−.424	−.626	−.876	−1.016	−.700	−.564	−.304
4	−.090	−.271	−.458	−.650	−.824	−1.006	−1.156	−1.335	−1.323	−.463	−.386	−.341
5	−.488	−.610	−.701	−.787	−.852	−.898	−1.005	−.985	−.671	−.372	−.351	−.324
6	−.767	−.816	−.819	−.804	−.784	−.653	−.534	−.434	−.312	−.448	−.411	−.361
7	−.665	−.698	−.651	−.467	−.267	−.063	.012	.018	−.286	−.370	−.346	−.300
8	−.216	−.228	−.228	−.245	−.311	−.442	−.622	−.549	−.039	.232	.484	.688
9	−.220	−.225	−.226	−.251	−.340	−.496	−.586	−.115	.205	.323	.463	.605
10	−.237	−.252	−.250	−.268	−.339	−.453	−.309	.069	.155	.235	.343	.464
11	−.247	−.260	−.269	−.301	−.345	−.240	.061	.086	.126	.174	.231	.314
12	−.258	−.255	−.250	−.261	−.215	007	.086	.081	.086	.084	.134	.197
13	−.186	−.199	−.189	−.156	.022	.149	.127	.093	.064	−.007	.017	.049

$V/c=0.80$

1	1.158	1.155	1.149	1.130	1.102	1.068	1.008	0.931	0.835	0.716	0.565	0.394
2	1.066	.992	.905	.794	.680	.571	.450	.310	.161	.002	−.159	−.311
3	.612	.463	.278	.118	−.032	−.184	−.325	−.483	−.578	−.570	−.404	−.277
4	.029	−.161	−.353	−.560	−.760	−.888	−.924	−.854	−.502	−.378	−.312	−.304
5	−.433	−.593	−.756	−.883	−.924	−.866	−.660	−.545	−.426	−.379	−.353	−.302
6	−.736	−.802	−.838	−.887	−.632	−.427 −.407	−.401	−.415	−.434	−.425	−.408	−.366
7	−.557	−.572	−.548	−.425	−.223	−.192	−.256	−.324	−.354	−.349	−.337	−.297
8	−.172	−.187	−.208	−.241	−.360	−.562	−.774	−.677	−.239	.310	.543	.758
9	−.176	−.186	−.200	−.241	−.371	−.646	−.695	−.366	.163	.344	.510	.668
10	−.186	−.198	−.227	−.259	−.367	−.524	−.296	−.027	.151	.264	.387	.511
11	−.194	−.214	−.246	−.284	−.353	−.307 −.229	−.002	.062	.111	.186	.262	.347
12	−.228	−.243	−.254	−.269	−.271	−.092	.030	.032	.059	.104	.154	.221
13	−.150	−.171	−.184	−.180	−.088	.036	.000	−.025	−.021	.000	.033	.066

$V/c=0.95$

1	1.230	1.229	1.221	1.206	1.182	1.148	1.102	1.048	0.975	0.868	0.729	0.571
2	1.143	1.077	1.000	.910	.811	.705	.591	.476	.356	.219	065	−.111
3	.724	.592	.447	.297	.158	.031	−.100	−.270	−.428	−.468	−.287	−.230
4	.168	.006	−.175	−.347	−.499	−.592	−.552	−.595	−.703	−.358	−.275	−.282
5	−.357	−.473	−.580	−.653	−.587	−.387	−.348	−.333	−.325	−.342	−.294	−.264
6	−.514	−.510	−.493	−.411	−.304	−.301	−.333	−.350	−.363	−.348	−.323	−.302
7	−.383	−.382	−.368	−.315	−.258	−.292	−.326	−.342	−.341	−.310	−.299	−.269
8	−.226	−.246	−.269	−.322	−.428	−1.098	−1.014	−.857	−.454	.208	.535	.759
9	−.231	−.249	−.266	−.315	−.417	−1.032	−.900	−.667	.002	.361	.520	.684
10	−.248	−.266	−.289	−.348	−.433	−.562	−.574	−.010	.137	.267	.404	.534
11	−.259	−.279	−.302	−.340	−.419	−.152	.072	.077	.112	.188	.277	.364
12	−.260	−.277	−.304	−.342	−.383	−.062	.071	.035	.062	.108	.162	.235
13	−.224	−.235	−.252	−.261	−.285	−.102	−.014	−.014	.000	.027	.058	.098

$V/c=1.08$

1	1.284	1.293	1.296	1.277	1.243	1.197	1.150	1.097	1.036	0.941	0.827	0.763
2	1.197	1.139	1.068	.980	.889	.790	.685	.583	.478	.358	.223	.053
3	.791	.669	.540	.419	.291	.171	.044	−.123	−.268	−.371	−.390	−.185
4	.264	.110	−.045	−.193	−.328	−.435	−.415	−.309	−.294	−.297 −.360	−.244 −.282	−.221
5	−.246	−.372	−.469	−.480	−.404	−.504 −.337	−.279	−.283	−.265	−.246	−.229	−.216
6	−.342	−.350	−.343	−.305	−.254	−.281	−.291	−.297	−.299	−.283	−.275	−.252
7	−.321	−.315	−.307	−.287	−.248	−.269	−.294	−.309	−.297	−.283	−.261	−.249
8	−.228	−.252	−.266	−.307	−.928	−.865	−.760	−.466	−.448	.220	.562	.784
9	−.230	−.252	−.268	−.315	−.889	−.783	−.642	−.439	−.125	.396	.544	.708
10	−.254	−.275	−.290	−.334	−.754	−.621	−.449	−.219	.101	.269	.420	.548
11	−.268	−.285	−.299	−.334	−.523	−.566	−.389	−.192	.060	.164	.279	.371
12	−.260	−.279	−.291	−.320	−.241	−.140	−.107	.068	.069	.060	.138	.232
13	−.228	−.249	−.274	−.293	−.159	−.034	.127	.126	.030	.040	.061	.113

LIFT COEFFICIENTS, C_L

AIRFOIL 1

V/c	Angle of attack											
	−20°	−16°	−12°	−8°	−4°	0°	4°	8°	12°	16°	20°	24°
0. 50	−0. 201	−0. 177	−0. 139	−0. 060	0. 075	0. 215	0. 401	0. 522	0. 646	0. 761	0. 830	0. 705
. 65	−. 184	−. 157	−. 114	−. 037	. 070	. 214	. 390	. 496	. 629	. 713	. 657	. 673
. 80	−. 150	−. 106	−. 058	. 003	. 054	. 205	. 354	. 484	. 559	. 608	. 626	. 648
. 95	−. 152	−. 110	−. 046	. 024	. 027	. 158	. 253	. 379	. 458	. 522	. 579	. 613
1. 08	−. 213	−. 161	−. 106	−. 124	−. 136	. 040	. 148	. 289	. 409	. 491	. 542	. 597

AIRFOIL 2

0. 50	−0. 148	−0. 120	−0. 074	0. 007	0. 135	0. 256	0. 408	0. 553	0. 651	0. 794	0. 851	0. 639
. 65	−. 125	−. 075	−. 022	. 042	. 095	. 238	. 391	. 518	. 622	. 700	. 604	. 663
. 80	−. 054	−. 011	. 036	. 067	. 129	. 243	. 361	. 487	. 536	. 573	. 572	. 614
. 95	−. 114	−. 064	. 000	. 035	. 068	. 098	. 196	. 336	. 460	. 506	. 545	. 574
1. 08	−. 192	−. 144	−. 119	−. 156	−. 198	−. 035	. 123	. 232	. 353	. 459	. 529	. 539

AIRFOIL 3

0. 50	−0. 098	−0. 047	0. 020	0. 093	0. 196	0. 282	0. 431	0. 580	0. 663	0. 786	0. 881	0. 586
. 65	−. 045	. 007	. 064	. 094	. 144	. 268	. 415	. 531	. 619	. 682	. 610	. 638
. 80	. 007	. 056	. 080	. 103	. 152	. 260	. 369	. 465	. 498	. 516	. 549	. 595
. 95	−. 063	−. 001	. 012	. 023	. 019	. 087	. 197	. 299	. 395	. 453	. 513	. 549
1. 08	−. 159	−. 136	−. 119	−. 121	−. 205	−. 062	. 106	. 221	. 310	. 402	. 470	. 518

AIRFOIL 4

0. 50	0. 024	0. 069	0. 140	0. 199	0. 237	0. 320	0. 476	0. 550	0. 684	0. 795	0. 536	0. 562
. 65	. 079	. 133	. 191	. 199	. 209	. 297	. 405	. 496	. 617	. 559	. 550	. 606
. 80	. 102	. 149	. 174	. 217	. 216	0. 283, 0. 265	. 313	. 378	. 411	. 480	. 525	. 604
. 95	. 021	. 039	. 054	. 056	. 089	. 096	. 143	. 229	. 335	. 419	. 465	. 519
1. 08	−. 124	−. 110	−. 102	−. 106	−. 229	−. 088	. 060	. 159	. 257	. 358	. 431	. 525

AIRFOIL 5

0. 50	0. 066	0. 131	0. 201	0. 257	0. 238	0. 338	0. 490	0. 603	0. 665	0. 778	0. 900, 0. 821	0. 521
. 65	. 123	. 181	. 242	. 232	. 233	. 299	. 454	. 528	. 591	. 475	. 515	. 575
. 80	. 111	. 176	. 222	. 256	. 208	0. 214, 0. 178	. 266	. 344	. 388	. 476	. 501	. 540
. 95	−. 027	−. 001	. 008	. 000	−. 074	−. 001	. 121	. 221	. 307	. 447	. 499	. 512
1. 08	−. 118	−. 122	−. 094	−. 121	−. 260	−. 133	. 010	. 152	. 217	. 333	. 410	. 487

AIRFOIL 6

0. 50	0. 150	0. 218	0. 285	0. 316	0. 284	0. 371	0. 470	0. 585	0. 668	0. 794	0. 488	0. 469
. 65	. 225	. 283	. 314	. 296	. 308	. 329	. 426	. 532	. 616	. 446	. 473	. 490
. 80	. 187	. 241	. 280	. 286	. 198	0. 190, 0. 210	. 264	. 329	. 358	. 423	. 462	. 494
. 95	−. 010	. 013	. 028	. 000	−. 089	−. 046	. 060	. 190	. 310	. 366	. 405	. 465
1. 08	−. 103	−. 088	−. 075	−. 102	−. 262	−. 133, −. 171	−. 039	. 098	. 181	. 304	. 381	. 423

DRAG COEFFICIENTS, C_D

AIRFOIL 1

V/c	Angle of attack											
	−20°	−16°	−12°	−8°	−4°	0°	4°	8°	12°	16°	20°	24°
0.50	0.185	0.149	0.124	0.079	0.053	0.042	0.045	0.059	0.085	0.123	0.165	0.286
.65	.181	.151	.117	.083	.057	.044	.047	.063	.095	.140	.230	.291
.80	.180	.148	.119	.086	.068	.050	.057	.080	.119	.174	.231	.287
.95	.197	.160	.131	.105	.083	.071	.082	.107	.144	.183	.233	.275
1.08	.217	.179	.148	.124	.101	.083	.088	.108	.144	.190	.235	.284

AIRFOIL 2

0.50	0.196	0.164	0.132	0.101	0.079	0.065	0.067	0.086	0.106	0.152	0.188	0.298
.65	.194	.163	.133	.107	.079	.067	.072	.085	.110	.156	.249	.314
.80	.186	.161	.136	.115	.092	.086	.079	.102	.138	.205	.251	.301
.95	.214	.185	.157	.133	.110	.096	.102	.127	.173	.220	.263	.303
1.08	.241	.206	.179	.157	.134	.110	.109	.128	.166	.208	.255	.302

AIRFOIL 3

0.50	0.202	0.168	0.139	0.115	0.092	0.075	0.078	0.097	0.112	0.150	0.203	0.280
.65	.196	.170	.147	.123	.095	.081	.083	.098	.117	.210	.266	.314
.80	.197	.176	.158	.136	.110	.092	.095	.122	.166	.209	.262	.311
.95	.230	.200	.179	.157	.135	.118	.122	.139	.173	.207	.262	.302
1.08	.260	.232	.204	.179	.159	.131	.133	.145	.168	.207	.249	.303

AIRFOIL 4

0.50	0.194	0.172	0.148	0.130	0.101	0.079	0.088	0.091	0.116	0.150	0.257	0.298
.65	.192	.172	.157	.136	.105	.089	.088	.096	.126	.202	.271	.327
.80	.199	.184	.169	.150	.123	.104	.110	.141	.178	.226	.268	.312
.95	.243	.220	.199	.183	.160	.147	.149	.163	.190	.220	.271	.319
1.08	.278	.252	.228	.205	.186	.157	.153	.163	.186	.223	.270	.338

AIRFOIL 5

0.50	0.212	0.189	0.167	0.151	0.112	0.090	0.093	0.099	0.105	0.135	0.313, 0.175	0.289
.65	.214	.198	.183	.158	.127	.101	.112	.105	.127	.203	.247	.304
.80	.231	.213	.198	.178	.145	.128	.139	.160	.193	.240	.282	.321
.95	.276	.259	.230	.210	.188	.170	.168	.185	.205	.253	.289	.318
1.08	.309	.283	.255	.230	.209	.178	.168	.173	.194	.225	.260	.307

AIRFOIL 6

0.50	0.224	0.205	0.194	0.176	0.135	0.122	0.109	0.111	0.125	0.169	0.193	0.302
.65	.228	.216	.207	.183	.150	.119	.118	.134	.206	.241	.278	.317
.80	.240	.225	.213	.202	.176	.162	.176	.195	.218	.254	.300	.340
.95	.298	.274	.259	.237	.215	.199	.194	.203	.227	.255	.298	.341
1.08	.330	.304	.280	.261	.238	0.208, 0.211	.196	.200	.211	.245	.285	.347

MOMENT COEFFICIENTS

AIRFOIL 1

V/c	Angle of attack											
	−20°	−16°	−12°	−8°	−4°	0°	4°	8°	12°	16°	20°	24°
0.50	−0.041	−0.030	−0.019	0.026	0.112	0.156	0.173	0.184	0.199	0.208	0.209	0.268
.65	−.028	−.019	.000	.043	.113	.155	.174	.174	.198	.196	.258	.277
.80	.000	.017	.039	.067	.097	.155	.166	.171	.183	.220	.251	.266
.95	.010	.022	.049	.082	.081	.164	.167	.178	.205	.223	.242	.242
1.08	−.022	.006	.030	.017	.052	.125	.158	.166	.181	.211	.228	.239

AIRFOIL 2

0.50	−0.013	−0.003	0.019	0.059	0.144	0.193	0.198	0.212	0.217	0.227	0.222	0.283
.65	.004	.028	.050	.081	.128	.178	.197	.188	.199	.204	.270	.295
.80	.053	.072	.092	.100	.138	.182	.186	.184	.192	.243	.254	.269
.95	.028	.052	.078	.081	.091	.148	.160	.188	.217	.239	.252	.255
1.08	−.011	.012	.017	−.005	.028	.097	.154	.172	.183	.208	.228	.243

AIRFOIL 3

0.50	0.005	0.028	0.065	0.104	0.152	0.188	0.211	0.223	0.218	0.228	0.233	0.261
.65	.045	.068	.093	.100	.130	.183	.205	.199	.199	.274	.273	.284
.80	.084	.103	.113	.108	.130	.174	.184	.193	.211	.229	.255	.269
.95	.054	.081	.075	.068	.066	.148	.173	.193	.210	.224	.244	.252
1.08	.000	.007	.009	.003	.023	.085	.157	.179	.180	.203	.220	.241

AIRFOIL 4

0.50	0.065	0.092	0.125	0.156	0.174	0.207	0.231	0.216	0.223	0.228	0.248	0.256
.65	.109	.132	.159	.153	.153	.194	.200	.190	.199	.245	.260	.279
.80	.127	.151	.152	.158	.150	0.198, .205	.175	.196	.208	.229	.246	.269
.95	.099	.095	.091	.080	.171	.137	.163	.181	.201	.209	.230	.247
1.08	.007	.012	.017	.005	.013	.077	.144	.168	.176	.188	.210	.232

AIRFOIL 5

0.50	0.090	0.121	0.154	0.179	0.156	0.208	0.233	0.228	0.209	0.219	0.260, 0.272	0.240
.65	.129	.159	.182	.160	.155	.190	.233	.205	.195	.217	.232	.257
.80	.132	.163	.176	.180	.138	0.141, .151	.174	.193	.203	.226	.240	.251
.95	.055	.062	.058	.048	.016	.114	.162	.180	.195	.223	.233	.239
1.08	.007	.002	.010	−.009	.000	.067	.129	.171	.165	.179	.199	.222

AIRFOIL 6

0.50	0.135	0.167	0.197	0.205	0.165	0.222	0.233	0.226	0.220	0.241	0.185	0.229
.65	.188	.214	.218	.190	.192	.197	.211	.213	.261	.229	.234	.238
.80	.160	.187	.190	.184	.128	.158	.185	.204	.222	.224	.242	.248
.95	.052	.063	.063	.043	−.003	.087	.151	.178	.199	.208	.232	.243
1.08	.003	.009	.012	−.003	−.011	0.042, .058	.114	.162	.167	.180	.204	.230

CENTER OF PRESSURE COEFFICIENTS

AIRFOIL 1

V/c	Angle of attack											
	−20°	−16°	−12°	−8°	−4°	0°	4°	8°	12°	16°	20°	24°
0. 50	0. 16	0. 14	0. 12	−0. 37	1. 58	0. 73	0. 43	0. 35	0. 31	0. 27	0. 25	0. 35
. 65	. 12	. 10	. 00	−. 90	1. 71	. 72	. 44	. 35	. 31	. 27	. 37	. 38
. 80	. 00	−. 12	−. 48	−7. 44	1. 98	. 76	. 47	. 35	. 32	. 35	. 38	. 38
. 95	−. 05	−. 15	−. 67	9. 11	3. 86	1. 04	. 65	. 46	. 43	. 40	. 39	. 36
1. 08	. 08	−. 03	−. 22	−. 12	−. 37	3. 13	1. 03	. 55	. 42	. 40	. 39	. 36

AIRFOIL 2

0. 50	0. 06	0 02	−0. 20	−8. 43	1. 12	0. 75	0. 48	0. 38	0. 33	0. 28	0. 26	0. 40
. 65	−. 02	−. 24	−1. 02	3. 11	1. 27	. 75	. 50	. 36	. 32	. 28	. 41	. 40
. 80	−. 47	−1. 31	13. 14	1. 96	1. 13	. 75	. 51	. 37	. 35	. 40	. 41	. 39
. 95	−. 16	−. 46	−2. 33	5. 06	1. 52	1. 51	. 79	. 54	. 45	. 44	. 42	. 39
1. 08	. 04	−. 06	−. 11	. 03	−. 14	−2. 77	1. 18	. 70	. 48	. 42	. 39	. 40

AIRFOIL 3

0. 50	−0. 03	−0. 30	−7. 22	1. 37	0. 80	0. 67	0. 49	0. 38	0. 32	0. 29	0. 26	0. 40
. 65	−. 41	−1. 66	2. 82	1. 32	. 95	. 68	. 49	. 37	. 32	. 38	. 41	. 40
. 80	−1. 38	17. 16	2. 51	1. 30	. 90	. 67	. 49	. 40	. 40	. 41	. 42	. 40
. 95	−. 39	−1. 45	−2. 88	68. 00	6. 60	1. 70	. 84	. 61	. 50	. 46	. 43	. 40
1. 08	. 00	−. 04	−. 06	−. 02	−. 11	−1. 37	1. 37	. 75	. 53	. 46	. 42	. 40

AIRFOIL 4

0. 50	−1. 48	4. 84	1. 18	0. 87	0. 76	0. 65	0. 48	0. 39	0. 32	0. 28	0. 42	0. 40
. 65	13. 62	1. 65	1. 03	. 86	. 76	. 65	. 49	. 38	. 32	. 41	. 43	. 41
. 80	4. 54	1. 62	1. 13	. 81	. 72	. 75, . 72	. 55	. 50	. 47	. 44	. 42	. 40
. 95	−1. 57	−4. 13	8. 27	2. 67	−6. 45	3. 72	1. 07	. 72	. 55	. 45	. 43	. 41
1. 08	−. 03	−. 07	−. 12	−. 04	−. 05	−. 88	2. 06	. 93	. 61	. 46	. 42	. 38

AIRFOIL 5

0. 50	−8. 18	1. 64	0. 95	0. 77	0. 68	0. 62	0. 47	0. 37	0. 31	0. 28	0. 29, 0. 31	0. 41
. 65	3. 00	1. 33	. 92	. 77	. 69	. 64	. 51	. 38	. 32	. 42	. 41	. 40
. 80	5. 28	1. 48	1. 00	. 79	. 70	0. 70, . 79	. 63	. 53	. 49	. 43	. 42	. 40
. 95	−. 42	−. 89	−1. 45	−1. 65	−. 18	−114. 00	1. 23	. 73	. 57	. 45	. 41	. 40
1. 08	−. 03	−. 01	−. 07	. 06	. 00	−. 50	5. 86	. 98	. 65	. 47	. 42	. 40

AIRFOIL 6

0. 50	2. 11	1. 09	0. 83	0. 71	0. 60	0. 60	0. 49	0. 38	0. 32	0. 30	0. 35	0. 42
. 65	1. 41	1. 01	. 83	. 71	. 65	. 62	. 49	. 39	. 40	. 46	. 43	. 41
. 80	1. 70	1. 10	. 83	. 72	. 69	0. 75, . 83	. 67	. 58	. 56	. 47	. 45	. 42
. 95	−. 46	−. 98	−2. 33	−1. 30	. 03	−1. 89	2. 07	. 82	. 57	. 49	. 48	. 43
1. 08	−. 01	−. 05	−. 09	. 02	. 04	−. 32, −. 34	−4. 56	1. 30	. 76	. 51, . 50	. 45	. 44

REPORT No. 256

THE AIR FORCES ON A SYSTEMATIC SERIES OF BIPLANE AND TRIPLANE CELLULE MODELS

By MAX M. MUNK
Langley Memorial Aeronautical Laboratory

REPORT No. 256

THE AIR FORCES ON A SYSTEMATIC SERIES OF BIPLANE AND TRIPLANE CELLULE MODELS

By MAX M. MUNK

SUMMARY

The air forces on a systematic series of biplane and triplane cellule models, measured in the atmospheric density tunnel of the Langley Memorial Aeronautical Laboratory, are the subject of this report. The tests consist in the determination of the lift, drag, and moment of each individual airfoil in each cellule. In most tests R. A. F.–15 were used.

The magnitude of the gap and of the stagger is systematically varied; (not, however, the decalage, which is zero throughout the tests). Certain check tests with a second wing section make the tests more complete, and the conclusions more convincing.

The results give evidence that the present Army and Navy specifications for the relative lifts of biplanes in the neighborhood of maximum lift are good. They furnish material for improving such specifications for the relative lifts of triplanes. A larger number of factors can now be prescribed to take care of different cases.

INTRODUCTION

The investigation reported here grew out of the needs of the practice. The Bureau of Aeronautics, United States Navy Department, wanted fuller information on the share of each individual wing of a biplane and triplane cellule in the creation of the lift of the entire cellule. Not only the desired lifts but also the drag and moment of all individual wings were determined, since this could be done conveniently at the same time.

It was realized from the beginning that decalage, i. e., a difference between the angle of attack of the individual airfoils of a cellule has a major influence on the relative lift contribution of each airfoil. (Reference 1). However, the cellules anticipated for use in practice are without decalage, and it is this specialization which made the following investigation practical. Otherwise, the number of the variations would become too large, and the material presented would become too voluminous.

The method used is not novel, but is well known to most of the readers. The airfoil model, geometrically similar to an airplane airfoil, but having a rectangular plan form, is fastened to a system of balances, and is then exposed to the constant air flow of the wind tunnel. Additional airfoils are placed in the neighborhood of the airfoil undergoing the tests, so as to form the desired cellule together with this latter airfoil. These additional airfoils, however, are not in mechanical connection with the balances. The airfoil under test, by varying the position of the additional airfoil or airfoils, is thus made to play the part of any airfoil of any cellule of the series. In each case the angle of attack of the whole set of airfoils is changed by steps. The air velocity is kept constant for all tests.

The details of this interesting and important research will be found in the body of this report. The results are laid down in numerical tables, and are illustrated by diagrams attached to this report. They are further discussed to lead the reader's attention to the main features brought out.

This has, however, been restricted to the discussion of the relative lifts, i. e., of the ratio of the lift of each airfoil to the lift of the entire cellule. It is true that this report contains plenty of material suitable for elucidating other wing problems. However, the discussion of such more general questions should be extended to all material available; it should not be restricted to the following tests alone. Further, the question of the tunnel wall interference has not been entirely settled as this paper is closed. An investigation of this question of the wall influence is just under way at the Langley Memorial Aeronautical Laboratory, and the use of the material of this report on general questions referring to the wing drag is better delayed until this investigation is finished. All data given in this report are computed directly from the observations without any correction for wall effect. It is realized that there probably is a wall effect, but only a small one.

TESTS

The atmospheric density tunnel in which the tests were made, the auxiliary apparatus and the wire balance used for the tests, are described in detail in Reference 2.

The set-up was composed of rectangular airfoils measuring 4 by 24 in. (101.6 by 609.6 mm.) in plan. R. A. F. 15 wings were furnished by the Navy. They were made of bronze. Measured at two stations along the span, their ordinates showed a maximum departure of 0.003 in. (0.076 mm.) from the specified ones. U. S. A. T. S. 5 airfoils were constructed in the N. A. C. A. shops out of laminated maple and were exact up to 0.004 in. (0.102 mm). None of the airfoils had any measurable warp or twist. The specified ordinates for both profiles are given in Table 1.

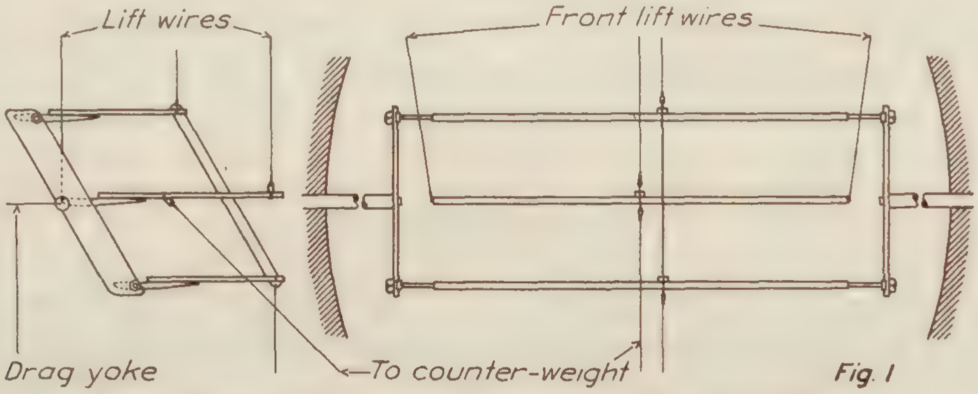


Fig. 1

Diagram showing arrangement and method of supporting wing model

The lift, drag, and pitching moment of each airfoil were measured. The air speed was 98.4 ft./sec. (30 m/sec.) throughout all tests, which corresponds to a dynamic pressure of 11.5 lb./sq. ft. (56.1 kg/m^2). It gives approximately the Reynolds Number, 206,000, with the chord as characteristic length.

The angle of attack was measured in the usual way. The absence of decalage was made certain by successively hanging an inclinometer on the wings after the wind tunnel flow was started and by adjusting the angle of attack of the fixed wing according to the readings of this inclinometer.

Supplemental tests were made to determine the wire drag and to obtain information about the interference of the side plates. This interference was found to be reasonably small.

All readings were made with the usual precision. The lift balance was read to ±0.005 kg (0.011 lb.) exactness and could be consistently checked within an interval of that magnitude. Drags were read to 0.0001 kg (0.0002 lb.) and repeated observations disagreed by less than ±0.0003 kg (±0.0007 lb.) at minimum drag. Moments measured as forces at the end of a 30.48 cm (12 in.) arm were read exact to 0.001 kg (0.002 lb.); they could be checked within ±0.002 kg (±0.004 lb.) interval.

The angles of attack which appear in the data have not been corrected for elastic deflections. Such deflections gave rise to errors of the angle of attack up to as much as one-third degree. However, this occurred only in the neighborhood of the maximum lift, where the curve of lift coefficient versus angle of attack is relatively flat. The average error is much smaller and mostly less than 0.1°.

One single airfoil and the following 29 cellules were tested, all composed of rectangular airfoils with the aspect ratio 6.

Monoplane with R. A. F. 15 section

Biplanes with U. S. A. T. S. 5 section

Stagger	Gap/chord
−30°	0. 9
0°	0. 9
+30	0. 9

Biplanes with R. A. F. 15 section

Stagger	Gap/chord
−30°	0. 6, 0. 9, 1. 2
0°	0. 6, 0. 8, 1. 0, 1. 2
+15°	0. 6, 0. 9, 1. 2
30°	0. 6, 0. 9, 1. 2

Triplanes with R. A. F. 15 section

Stagger	Gap/chord
−30°	0. 6, 0. 9, 1. 2
0°	0. 6, 0. 8, 1. 0, 1. 2
+15°	0. 6, 0. 9, 1. 2
30°	0. 6, 0. 9, 1. 2

Lift, drag, and moment coefficients were calculated in the usual manner:

$$C_L=\frac{L}{qS} \qquad C_D=\frac{D}{qS} \qquad C_M=\frac{M}{qcS}$$

wherein:

L = Lift.
D = Drag.
M = Pitching moment.
$-M$ = Diving moment.
q = Dynamic pressure.
S = Wing area.
c = Wing chord.

Moment coefficients refer to the leading edges of the individual wings. They are counted negative when they are diving moments in accordance with the standards laid down in Reference 6. Within the investigated range of the angle of attack the pitching moment is generally negative. As most readers are accustomed to have positive values plotted, and as the pitching moment is counted opposite in many older publications here and abroad, the coefficient of diving moment—that is, $(-C_M)$—rather than the coefficient of pitching moment has been plotted in all diagrams.

RESULTS

The results of the biplane and triplane tests are given in Tables 2 to 41 and are illustrated by Figures 2 to 68.

In Table 2 are the lift and drag coefficients of a R. A. F. 15 airfoil as determined by tests with and without the supports for additional wings. Figure 2 contains the corresponding polar curves.

Tables 3 to 15 contain the lift, drag, and moment coefficients for each wing of the R. A. F. 15 biplane combinations for all angles of attack.

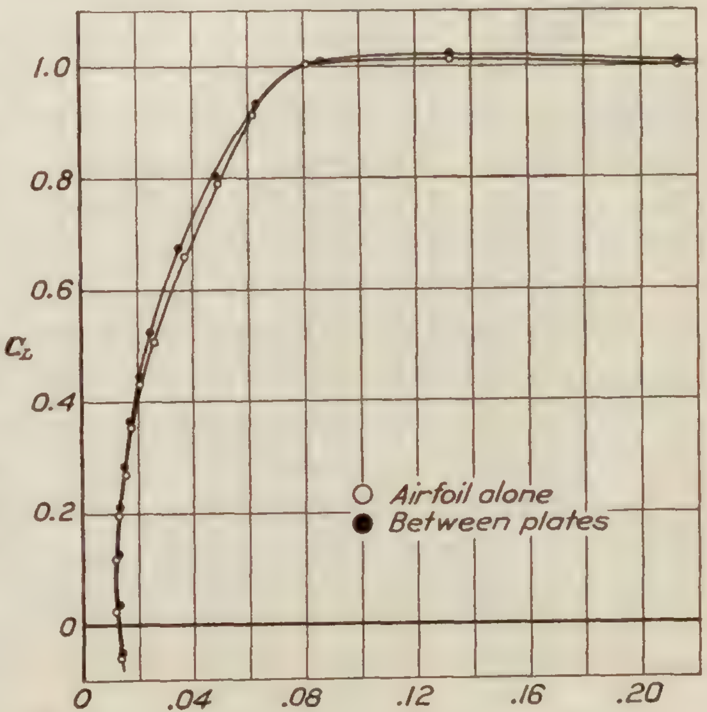


Fig. 2

Polar curve for single airfoil R. A. F. 15 measured alone and between supporting plates

The results of the U. S. A. T. S. 5 biplane tests and the R. A. F. 15 triplane tests are presented in the same form and order in Tables 17 to 19 and 21 to 33.

Figures 3 to 15 contain the polar and moment curves of the individual wings of the R. A. F. 15 biplane cellules. Inserted into the same figures are the curves of individual lift coefficients, C_{LW}, versus cellule lift coefficient, C_{LC}. Figures 16 to 18 are the curves of relative lift versus stagger.

Figures 19 to 21 illustrate the results of the U. S. A. T. S. 5 biplane and Figures 23 to 38 those of the R. A. F. 15 triplane tests in a corresponding manner.

The relative lifts of the individual members of all the tested biplane and triplane cellules have been computed for 0.9, 0.5, and 0.25 of the maximum cellule lift coefficient. Tables 16, 20, and 34 contain the relative lifts for R. A. F. 15 biplane, U. S. A. T. S. 5 biplane, and R. A. F. 15 triplane models.

0.9 of the maximum lift coefficient is considered the upper limit of the lift coefficient for dangerous air loads occurring when the airplane is pulled out of a dive. 0.5 is considered the lower limit. The third value, 0.25 maximum lift coefficient, has been added to take care of extreme cases such as racers.

Figures 40 to 68 illustrate the positions of the centers of pressure of the individual wings plotted against the angle of attack of the cellule.

DISCUSSION

The results of the tests with all models show that there is a general tendency of the upper wing to contribute more of the lift than the lower at positive stagger and less at negative stagger. With negative lifts this is naturally reversed, since upper and lower refer primarily to the direction of the lift. This result was to be expected from theoretical considerations (Reference 3).

The variation of gap/chord causes small changes in the relative lifts at high lift coefficients and large changes at low lift coefficients. An increase of gap tends to equalize the lift of the wings over the entire range of the angle of attack. This includes also the lift contribution of the wing model of a triplane cellule. Nor does the change of the wing section of the biplane cellule upset this rule, which is natural and expected.

The middle wing of triplane cellules contributes less lift than either of the other two wings, as shown by Figures 36 to 38.

The relative lift of any one airfoil may vary as much as 0.11, as the lift coefficient of the combustion increases from 0.25 to 0.9 of the maximum lift coefficient. This occurred in an extreme case, with the R. A. F. biplane with −30° stagger and the gap/chord 0.6, as shown in Table 16.

Figure 22 contains a curve of relative lifts at 0.9 maximum cellule lift, which for different staggers and for the U. S. A. T. S. 5 section almost coincides with the corresponding curve for the R. A. F. 15 biplane. The difference between corresponding ordinates does not exceed 2½ per cent. At lower lift coefficients the differences become larger, but do not exceed 7 per cent at 0.25 maximum cellule lift. It was, therefore, considered unnecessary to repeat the investigation of the effect of different gaps with the U. S. A. T. S. 5 section.

At large lift coefficients the two biplane wings have about equal lifts at −15° stagger.

The results of the center of pressure computations show that the ratio of gap to chord has practically no effect on the positions of the centers of pressure of the individual wings in either the biplane or triplane combinations, at normal angles of attack of flight. With increase of positive stagger in biplane cellules the centers of pressure move forward on the upper wing and backward on the lower wing, and lie nearly together at 0° stagger. In the triplane cellules there is a forward motion on the upper and middle wings and a backward motion on the lower wing with the positions nearly coincident at 0° stagger.

CONCLUSIONS

The United States Army and Navy standard relative lifts for biplanes (References 4 and 5) are plotted for comparison in Figure 39. It will be seen that the agreement is very good at high lift coefficients. In the light of the described tests the specifications appear therefore to be good.

The present Army specification for the distribution of lift in triplane cellules is illustrated in Figures 36 to 38, and plotted together with the results of the foregoing tests. The study of these figures suggests the drafting of more specialized standards for triplanes. The effects of different stagger and gap/chord ratio should be taken into account, and triplanes of different speed ranges require different specifications.

REFERENCES

1. Munk, Max M.: Beitrag zur Aerodynamik der Flugzeugtragorgane. Technische Berichte, Vol. II, No. 2, 1918.
2. Reid, E. G.: Standardization Tests of N. A. C. A. No. 1 Wind Tunnel. N. A. C. A. Technical Report No. 195, 1924.
3. Munk, Max M.: General Biplane Theory. N. A. C. A. Technical Report No. 151, 1922.
4. Engineering Division United States Army Air Service: Handbook of Instructions for Airplane Designers, fourth edition, April, 1925. Section II, Figure 1.
5. Diehl, W. S.: The Relative Loading of Biplane Wings. Bureau of Aeronautics, United States Navy Department Technical Note No. 86, 1921.
6. National Advisory Committee for Aeronautics: Nomenclature for Aeronautics. N. A. C. A. Technical Report No. 25, 1919.

FURTHER LITERATURE ON THE SUBJECT

Pannell, J. R., and Griffiths, E. A.: Experiments on Models of Biplane Wings. British Advisory Committee for Aeronautics R. and M. No. 196, 1915.

Bryant, L. W., and Jones, Miss C. N.: Biplane Effect on R. A. F. 15 Wing Section. British Advisory Committee for Aeronautics R. and M. No. 366, 1917.

Cowley, W. L., and Levy, H.: Triplane Investigation with R. A. F. 15 Section. British Advisory Commitee for Aeronautics R. and M. No. 432, 1918.

Cowley, W. L., and Levy, H.: The Contribution of the Separate Planes to the Forces on a Biplane. British Advisory Committee for Aeronautics R. and M. No. 589, 1919.

Cowley, W. L., and Lock, C. N. H.: Biplane Investigation with R. A. F. 15 Section. British Advisory Committee for Aeronautics R. and M. No. 774, 1921.

Cowley, W. L., and Jones, L. J.: Biplane Investigation with R. A. F. 15 Section, Part II. British Advisory Committee for Aeronautics R. and M. No. 857, 1922.

Cowley, W. L., Gadd, A. G., Jones, J. L., and Skan, Miss S. W.: Biplane Investigation with R. A. F. 15 Section, Part III. British Advisory Committee for Aeronautics R. and M. No. 872, 1923.

Toussaint, A.: Etudes Systematiques sur les Biplanes. Service Technique de l'Aeronautique, March, 1923.

TABLE 1

R. A. F. 15 Airfoil ordinates

Station in inches from leading edge	Upper surface	Lower surface
Inch	*Inch*	*Inch*
0.000	+0.060	+0.060
.020	.091	.039
.040	.111	.033
.080	.144	.024
.200	.202	.009
.358	.237	.000
.400	.244	+.001
.600	.266	.012
.800	.278	.021
1.000	.280	.032
1.200	.277	.041
1.400	.273	.043
1.600	.265	.041
2.000	.244	.027
2.400	.219	.013
2.800	.191	.002
2.980	.177	.000
3.200	.158	+.002
3.600	.115	.008
3.800	.088	.013
3.920	.069	.017
4.000	.032	.032

U. S. A. T. S. 5 Airfoil ordinates

Station in inches from leading edge	Upper surface	Lower surface
Inches	*Inch*	*Inch*
0.00	+0.080	+0.080
.05	.176	.000
.10	.220	−.032
.20	.296	−.072
.30	.352	−.100
.40	.400	−.120
.60	.472	−.136
.80	.524	−.140
1.20	.588	−.116
1.60	.592	−.060
2.00	.556	−.026
2.40	.492	−.012
2.80	.412	−.008
3.20	.312	−.004
3.60	.196	.000
3.80	.132	.000
4.00	.040	+.040

TABLE 2

R. A. F. 15 Airfoil—interference tests

	Airfoil alone		Between plates	
α	C_L	C_D	C_L	C_D
Degrees				
−3	−0.063	+0.0140	−0.052	+0.0141
−2	+0.022	.0121	+0.034	.0129
−1	.116	.0120	.126	.0124
0	.199	.0132	.210	.0135
+1	.270	.0157	.282	.0151
2	.352	.0178	.366	.0167
3	.432	.0203	.443	.0201
4	.506	.0261	.522	.0242
6	.659	.0370	.673	.0345
8	.790	.0490	.805	.0481
10	.915	.0617	.934	.0627
12	1.00	.0807	1.01	.0856
14	1.01	.133	1.02	.132
16	1.00	.213	1.01	.213

TABLE 3

R. A. F. 15 biplane. $G/c=0.6$. Stagger $=-30°$

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−4	−0.121	+0.0334	−0.015			
−3				−0.058	+0.0166	−0.025
−2				+.002	.0167	−.045
−1				.090	.0157	−.065
0				.173	.0159	−.089
+1				.234	.0177	−.105
2				.300	.0196	−.122
3	+.224	.0199	−.089	.357	.0215	−.134
4	.278	.0256	−.096	.414	.0244	−.141
6	.396	.0347	−.129	.523	.0307	−.167
8	.504	.0524	−.161	.631	.0408	−.192
10	.606	.0710	−.182	.736	.0485	−.202
12	.711	.0898	−.195	.817	.0636	−.227
14	.810	.0952	−.200	.844	.111	−.268
16	.807	.0934	−.150	.838	.193	−.286

TABLE 4

R. A. F. 15 biplane. $G/c=0.9$. Stagger $=-30°$

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−3	−0.072	+0.0149	−0.002	−0.084	+0.0173	−0.015
−2	−.009	.0130	−.021	−.010	.0167	−.035
−1	+.055	.0118	−.042	+.076	.0142	−.057
0	.118	.0127	−.072	.165	.0143	−.085
+1	.169	.0149	−.089	.230	.0157	−.104
2	.214	.0175	−.091	.294	.0174	−.118
3	.265	.0208	−.097	.368	.0201	−.132
4	.327	.0251	−.117	.427	.0228	−.148
6	.449	.0384	−.150	.558	.0299	−.171
8	.536	.0572	−.183	.679	.0421	−.194
10	.667	.0767	−.199	.796	.0510	−.224
12	.787	.0962	−.230	.865	.0669	−.250
14	.913	.109	−.245	.864	.108	−.269
16	.950	.130	−.256	.832		
18	.891	.153	−.270			

TABLE 5

R. A. F. 15 biplane. $G/c=1.2$. Stagger $=-30°$

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−3	−0.058	+0.0151	−0.013	−0.092	+0.0168	−0.008
−2	.000	.0139	−.034	−.018	.0164	−.029
−1	+.084	.0125	−.053	+.070	.0144	−.056
0	.144	.0139	−.080	.163	.0149	−.078
+1	.197	.0161	−.095	.229	.0170	−.100
2	.246	.0191	−.101	.297	.0186	−.112
3	.307	.0225	−.112	.374	.0213	−.135
4	.367	.0275	−.136	.442	.0242	−.148
6	.486	.0410	−.160	.573	.0323	−.174
8	.600	.0598	−.190	.706	.0446	−.211
10	.714	.0810	−.215	.814	.0549	−.222
12	.843	.100	−.249	.897	.0710	−.253
14	.970	.118	−.280	.888	.112	−.283
16	.975	.148	−.284	.850		

TABLE 6

R. A. F. 15 biplane. $G/c=0.6$. Stagger $=0°$

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−3	−0.066	+0.0169	0.000	+0.003	+0.0140	−0.039
−2	−.001	.0140	−.025	.065	.0132	−.061
−1	+.067	.0116	−.047	.096	.0131	−.085
0	.126	.0116	−.053	.146	.0150	−.091
+1	.183	.0115	−.073	.194	.0175	−.097
2	.254	.0129	−.084	.234	.0198	−.118
3	.314	.0152	−.112	.290	.0232	−.129
4	.373	.0185	−.118	.335	.0273	−.137
6	.488	.0244	−.125	.433	.0374	−.149
8	.605	.0395	−.161	.532	.0506	−.177
10	.730	.0532	−.190	.620	.0623	−.192
12	.838	.0669	−.223	.700	.0741	−.214
14	.912	.0834	−.230	.765	.0983	−.238
16	.911	.173	−.218	.799	.178	−.282

TABLE 7

R. A. F. 15 biplane. $G/c=0.8$. Stagger $=0°$

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−3	−0.055	+0.0161	−0.012	−0.040	+0.0137	−0.026
−2	−.018	.0139	−.024	+.002	.0125	−.047
−1	+.056	.0120	−.060	.059	.0118	−.061
0	.115	.0121	−.075	.112	.0129	−.086
+1	.160	.0130	−.080	.162	.0150	−.097
2	.236	.0144	−.098	.208	.0171	−.112
3	.299	.0174	−.117	.264	.0201	−.126
4	.350	.0208	−.128	.320	.0240	−.128
6	.472	.0308	−.155	.422	.0340	−.154
8	.606	.0460	−.199	.527	.0473	−.186
10	.731	.0625	−.214	.621	.0590	−.211
12	.845	.0776	−.236	.706	.0680	−.221
14	.931	.102	−.264	.756	.0975	−.242
16	.942	.142	−.269	.796	.173	−.283

TABLE 8

R. A. F. 15 biplane. $G/c=1.0$. Stagger $=0°$

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−3	−0.061	+0.0130	−0.015	−0.060	+0.0143	−0.027
−2	−.006	.0104	−.033	−.001	.0120	−.049
−1	+.063	.0090	−.055	+.064	.0113	−.069
0	.129	.0095	−.071	.129	.0125	−.087
+1	.182	.0105	−.089	.177	.0145	−.101
2	.248	.0120	−.103	.231	.0167	−.115
3	.319	.0153	−.122	.293	.0197	−.121
4	.380	.0213	−.140	.355	.0238	−.140
6	.509	.0326	−.166	.465	.0342	−.164
8	.639	.0487	−.191	.567	.0465	−.186
10	.770	.0655	−.210	.672	.0583	−.208
12	.889	.0815	−.225	.757	.0686	−.227
14	.968	.109	−.262	.808	.101	−.250
16	.988	.161	−.311	.833	.170	−.281

TABLE 9

R. A. F. 15 biplane. $G/c=1.2$. Stagger$=0°$

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−3	−0.066	+0.0147	−0.015	−0.055	+0.0148	−0.016
−2	−.001	.0121	−.033	+.015	.0132	−.041
−1	+.074	.0107	−.064	.080	.0118	−.066
0	.144	.0113	−.076	.149	.0126	−.082
+1	.197	.0128	−.084	.203	.0148	−.094
2	.267	.0148	−.111	.257	.0163	−.105
3	.333	.0180	−.121	.325	.0193	−.122
4	.402	.0225	−.139	.378	.0233	−.135,
6	.531	.0342	−.175	.501	.0335	−.165
8	.666	.0504	−.206	.620	.0471	−.191
10	.786	.0675	−.232	.730	.0597	−.207
12	.897	.0837	−.261	.815	.0705	−.235
14	--------	--------	--------	.860	.105	−.258
16	--------	--------	--------	.874	.178	−.298

TABLE 10

R. A. F. 15 biplane. $G/c=0.6$. Stagger$=+15°$

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−3	−0.057	+0.0180	0.000	+0.017	+0.0119	−0.038
−2	+.013	.0158	−.025	.085	.0117	−.060
−1	.096	.0142	−.049	.137	.0125	−.078
0	.159	.0133	−.070	.178	.0136	−.090
+1	.226	.0117	−.079	.213	.0154	−.091
2	.289	.0125	−.107	.257	.0177	−.106
3	.354	.0152	−.108	.312	.0213	−.120
4	.419	.0181	−.120	.366	.0269	−.131
6	.552	.0274	−.151	.462	.0398	−.150
8	.688	.0396	−.184	.554	.0546	−.192
10	.807	.0520	−.206	.654	.0702	−.206
12	.916	.0656	−.218	.737	.0833	−.235
14	.952	.0914	−.242	.803	.100	−.248
16	.901	.129	−.245	.877	.145	−.272

TABLE 11

R. A. F. 15 biplane. $G/c=0.9$. Stagger$=+15°$

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−3	−0.052	+0.0150	−0.003	−0.034	+0.0144	−0.023
−2	+.024	.0138	−.030	+.038	.0130	−.044
−1	.108	.0135	−.053	.103	.0128	−.065
0	.178	.0136	−.074	.160	.0139	−.074
+1	.238	.0137	−.094	.209	.0157	−.091
2	.307	.0152	−.099	.257	.0181	−.097
3	.379	.0177	−.121	.316	.0207	−.116
4	.450	.0205	−.133	.374	.0254	−.129
6	.584	.0304	−.162	.480	.0380	−.160
8	.717	.0440	−.189	.588	.0527	−.182
10	.865	.0622	−.220	.681	.0680	−.211
12	.970	.0783	−.251	.775	.0813	−.229
14	1.04	.108	−.270	.861	.100	−.248
16	1.01	.147	−.293	.923	.144	−.263

TABLE 12

R. A. F. 15 biplane. $G/c=1.2$. Stagger$=+15°$

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−3	−0.055	+0.0174	−0.012	−0.043	+0.0150	−0.012
−2	+.021	.0161	−.033	+.032	.0144	−.033
−1	.110	.0159	−.063	.102	.0143	−.055
0	.191	.0170	−.093	.164	.0159	−.082
+1	.249	.0173	−.105	.220	.0176	−.094
2	.326	.0180	−.120	.270	.0192	−.103
3	.400	.0206	−.132	.339	.0221	−.124
4	.468	.0245	−.145	.395	.0260	−.140
6	.609	.0356	−.175	.502	.0373	−.160
8	.751	.0503	−.212	.623	.0525	−.181
10	.896	.0693	−.241	.711	.0695	−.221
12	1.01	.0874	−.278	.811	.0833	−.241
14	1.05	.122	−.303	.908	.107	−.250
16	1.03	.178	−.334	.960	.149	−.291

TABLE 13

R. A. F. 15 biplane. $G/c=0.6$. Stagger$=+30°$

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−3	−0.020	+0.0162	−0.020	+0.016	+0.0123	−0.036
−2	+.057	.0153	−.041	.075	.0125	−.060
−1	.145	.0145	−.067	.116	.0134	−.061
0	.216	.0152	−.079	.152	.0163	−.084
+1	.295	.0156	−.103	.192	.0193	−.082
2	.364	.0174	−.116	.231	.0231	−.099
3	.438	.0192	−.130	.276	.0260	−.100
4	.500	.0221	−.144	.329	.0309	−.117
6	.639	.0298	−.176	.423	.0446	−.143
8	.787	.0428	−.208	.510	.0615	−.167
10	.912	.0552	−.234	.602	.0778	−.191
12	.997	.0779	−.228	.686	.0936	−.212
14	1.00	.124	−.291	.783	.115	−.238
16	.951	--------	−.292	.906	.157	−.279

TABLE 14

R. A. F. 15 biplane. $G/c=0.9$. Stagger$=+30°$

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−3	−0.052	+0.0156	−0.013	−0.028	+0.0132	−0.030
−2	+.028	.0161	−.027	+.041	.0128	−.047
−1	.120	.0158	−.058	.093	.0125	−.063
0	.208	.0166	−.099	.147	.0144	−.071
+1	.272	.0177	−.098	.202	.0168	−.087
2	.351	.0197	−.132	.241	.0197	−.094
3	.422	.0220	−.139	.300	.0228	−.109
4	.499	.0262	−.158	.353	.0280	−.120
6	.640	.0359	−.197	.452	.0412	−.154
8	.794	.0511	−.236	.556	.0572	−.185
10	.898	.0658	−.234	.662	.0748	−.200
12	1.03	.0832	−.248	.756	.0900	−.230
14	1.08	.130	−.312	.862	.110	−.256
16	1.05	.215	−.356	.964	.144	−.294

TABLE 15

R. A. F. 15 biplane. $G/c=1.2$. Stagger $=+30°$

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−3	−0.055	+0.0147	−0.016	−0.040	0.0152	−0.009
−2	+.032	.0149	−.048	+.032	.0157	−.044
−1	.122	.0145	−.071	.090	.0153	−.062
0	.214	.0153	−.095	.152	.0167	−.080
+1	.275	.0165	−.105	.213	.0189	−.092
2	.358	.0186	−.134	.257	.0219	−.103
3	.434	.0214	−.142	.320	.0251	−.117
4	.505	.0249	−.167	.374	.0297	−.137
6	.659	.0356	−.199	.489	.0424	−.161
8	.820	.0518	−.240	.600	.0594	−.191
10	.948	.0671	−.226	.709	.0759	−.216
12	1.05	.0864	−.252	.811	.0906	−.244
14	1.08	.137	−.326	.913	.110	−.267
16	1.06	.226	−.358	.974	.148	−.288

TABLE 16

R. A. F. 15 biplanes.

90% $C_{LC\,max}$						50% $C_{LC\,max}$					25% $C_{LC\,max}$				
G/c	90% $C_{LC\max}$	C_{LU}	C_{LL}	$\frac{C_{LU}}{C_{LC}}$	$\frac{C_{LL}}{C_{LC}}$	50% $C_{LC\max}$	C_{LU}	C_{LL}	$\frac{C_{LU}}{C_{LC}}$	$\frac{C_{LL}}{C_{LC}}$	25% $C_{LC\max}$	C_{LU}	C_{LL}	$\frac{C_{LU}}{C_{LC}}$	$\frac{C_{LL}}{C_{LC}}$
Stagger $=-30°$															
0.6	0.752	0.698	0.806	0.464	0.536	0.418	0.350	0.485	0.418	0.582	0.209	0.145	0.268	0.351	0.649
0.9	.807	.755	.850	.470	.530	.449	.387	.501	.435	.565	.224	.186	.256	.421	.579
1.2	.841	.810	.877	.480	.520	.468	.423	.508	.454	.546	.234	.215	.252	.460	.540
Stagger $=0°$															
0.6	0.771	0.840	0.700	0.545	0.455	0.429	0.452	0.398	0.531	0.469	0.214	0.213	0.217	0.495	0.505
0.8	.783	.857	.712	.546	.454	.435	.461	.411	.528	.472	.218	.222	.206	.519	.481
1.0	.820	.885	.754	.540	.460	.456	.478	.430	.526	.474	.228	.234	.222	.513	.488
1.2	.837	.873	.800	.521	.479	.465	.483	.445	.521	.479	.233	.241	.222	.520	.480
Stagger $=+15°$															
0.6	0.801	0.890	0.705	0.557	0.443	0.445	0.478	0.408	0.539	0.461	0.223	0.221	0.223	0.498	0.502
0.9	.873	.958	.785	.548	.452	.485	.528	.438	.547	.453	.243	.262	.224	.538	.462
1.2	.900	.995	.800	.554	.446	.500	.543	.454	.544	.456	.250	.271	.226	.545	.455
Stagger $=+30°$															
0.6	0.838	0.988	0.682	0.591	0.409	0.466	0.573	0.362	0.613	0.398	0.233	0.277	0.189	0.595	0.405
0.9	.914	1.05	.780	.574	.426	.508	.591	.418	.586	.414	.254	.287	.211	.576	.424
1.2	.923	1.05	.795	.567	.433	.512	.588	.434	.575	.425	.256	.292	.217	.571	.429

TABLE 17

U. S. A. T. S. 5 biplane. $G/c=0.9$. Stagger=−30°

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−9	--------	--------	--------	−0.004	+0.0132	−0.124
−7	+0.064	+0.0144	−0.178	+ .119	.0165	−.158
−5	.165	.0161	−.223	.246	.0217	−.182
−3	.268	.0209	−.254	.369	.0278	−.207
−1	.380	.0284	−.281	.489	.0358	−.237
0	.441	.0345	−.290	.548	.0400	−.244
+1	.493	.0409	−.313	.607	.0444	−.253
2	.554	.0473	−.326	.670	.0490	−.277
3	.609	.0562	−.347	.729	.0542	−.275
4	.670	.0658	−.354	.787	.0590	−.294
6	.783	.0857	−.384	.900	.0695	−.322
8	.895	.109	−.415	.999	.0800	−.348
10	1.01	.135	−.442	1.07	.0865	−.354
12	1.13	.162	−.468	1.09	.0999	−.346
14	1.22	.185	−.478	1.02	.120	−.329
16	1.25	.203	−.480	.958	.143	−.312
18	1.17	.216	−.425	--------	--------	--------
20	1.09	.223	−.423	--------	--------	--------

TABLE 18

U. S. A. T. S. 5 biplane. $G/c=0.9$. Stagger=0°

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−9	−0.026	+0.0257	−0.088	+0.040	+0.0036	−0.144
−7	+.091	.0242	−.118	.158	.0074	−.162
−5	.205	.0248	−.133	.272	.0139	−.192
−3	.325	.0279	−.169	.379	.0229	−.208
−1	.452	.0333	−.199	.486	.0330	−.243
0	.508	.0370	−.208	.536	.0385	−.252
+1	.574	.0412	−.238	.591	.0448	−.264
2	.635	.0464	−.250	.645	.0523	−.282
3	.697	.0520	−.255	.695	.0589	−.288
4	.758	.0556	−.279	.750	.0665	−.302
6	.887	.0734	−.308	.858	.0825	−.320
8	1.01	.0921	−.336	.956	.0960	−.348
10	1.13	.113	−.366	1.03	.113	−.365
12	1.21	.132	−.381	1.06	.124	−.367
14	1.23	.158	−.381	1.06	.139	−.351
16	1.22	.174	−.363	1.02	.158	−.341
--------	--------	--------	--------	--------	--------	--------
--------	--------	--------	--------	--------	--------	--------

TABLE 19

U. S. A. T. S. 5. biplane. $G/c=0.9$. Stagger=+30°

	Upper wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M
Degrees						
−9	+0.097	+0.0165	−0.125	+0.003	+0.0074	−0.099
−7	.229	.0180	−.157	.102	.0096	−.122
−5	.363	.0215	−.193	.203	.0154	−.148
−3	.504	.0264	−.232	.300	.0234	−.168
−1	.646	.0332	−.275	.395	.0347	−.192
0	.724	.0377	−.281	.447	.0418	−.213
+1	.804	.0428	−.305	.496	.0490	−.231
2	.890	.0486	−.323	.544	.0571	−.239
3	.965	.0553	−.359	.585	.0658	−.249
4	1.03	.0624	−.381	.635	.0755	−.261
6	1.18	.0774	−.415	.725	.0945	−.284
8	1.29	.0936	−.428	.823	.115	−.314
10	1.34	.114	−.426	.921	.136	−.335
12	1.35	.139	−.416	1.03	.160	−.370
14	1.31	.168	−.399	1.12	.182	−.393
16	1.25	.190	−.383	1.15	.207	−.398
18	1.15	.212	−.365	1.15	.231	−.395
20	--------	--------	--------	1.16	.262	−.401

TABLE 20

U. S. A. T. S. 5 biplanes.

90% C_{LC} max.						50% C_{LC} max.					25% C_{LC} max.				
G/c	90% C_{LC} max.	C_{LU}	C_{LL}	$\frac{C_{LU}}{C_{LC}}$	$\frac{C_{LL}}{C_{LC}}$	50% C_{LC} max.	C_{LU}	C_{LL}	$\frac{C_{LU}}{C_{LC}}$	$\frac{C_{LL}}{C_{LC}}$	25% C_{LC} max.	C_{LU}	C_{LL}	$\frac{C_{LU}}{C_{LC}}$	$\frac{C_{LL}}{C_{LC}}$
Stagger=−30°															
0.9	1.01	0.975	1.05	0.481	0.519	0.562	0.507	0.620	0.450	0.550	0.281	0.233	0.328	0.415	0.585
Stagger=0°															
0.9	1.03	1.07	1.00	0.518	0.482	0.575	0.562	0.583	0.493	0.507	0.287	0.257	0.317	0.447	0.553
Stagger=+30°															
0.9	1.10	1.32	0.868	0.604	0.396	0.609	0.757	0.463	0.620	0.380	0.305	0.387	0.221	0.638	0.363

TABLE 21

R. A. F. 15 triplane. $G/c=0.6$. Stagger $=-30°$

	Upper wing			Middle wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M	C_L	C_D	C_M
Degrees									
−4	−0.083	+0.0179	−0.002	−0.105	+0.0182	−0.012	---------	---------	---------
−3	---------	---------	---------	−.056	+.0170	−.036	−0.065	+0.0174	−0.025
−2	---------	---------	---------	---------	---------	---------	+.005	.0180	−.042
−1	---------	---------	---------	---------	---------	---------	.083	.0171	−.059
0	---------	---------	---------	---------	---------	---------	.161	.0173	−.093
+1	---------	---------	---------	---------	---------	---------	.232	.0186	−.110
2	---------	---------	---------	---------	---------	---------	.277	.0199	−.121
3	+.201	+.0185	−.083	---------	---------	---------	.345	.0222	−.133
4	.242	.0227	−.087	+.248	+.0212	−.088	.401	.0246	−.141
5	.290	.0285	−.096	.304	.0238	−.112	---------	---------	---------
6	.329	.0334	−.113	.352	.0291	−.118	511	.0320	−.155
8	.418	.0502	−.146	.434	.0409	−.138	.616	.0385	−.171
10	.541	.0723	−.172	.514	.0517	−.148	.715	.0474	−.208
12	.638	.0930	−.193	.602	.0609	−.165	.786	.0637	−.222
14	.744	.115	−.223	.680	.0622	−.176	.800	.113	−.247
16	.846	.126	−.233	.689	.0702	−.159	.756	.183	−.288
18	.868	.146	−.249	---------	---------	---------	---------	---------	---------

TABLE 22

R. A. F. 15 triplane. $G/c=0.9$. Stagger $=-30°$

	Upper wing			Middle wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M	C_L	C_D	C_M
Degrees									
−3	−0.035	+0.0135	−0.012	−0.075	+0.0163	−0.010	−0.083	+0.0164	−0.012
−2	+.002	.0127	−.032	−.025	.0143	−.023	−.014	.0162	−.029
−1	.062	.0122	−.048	+.013	.0126	−.037	+.070	.0158	−.058
0	.109	.0129	−.063	.102	.0134	−.066	.158	.0159	−.084
+1	.154	.0146	−.077	.157	.0154	−.084	.226	.0170	−.102
2	.200	.0168	−.084	.202	.0177	−.091	.286	.0170	−.110
3	.248	.0201	−.102	.245	.0205	−.094	.354	.0195	−.122
4	.289	.0240	−.105	.293	.0237	−.106	.421	.0221	−.132
6	.400	.0373	−.139	.405	.0333	−.131	.543	.0296	−.160
8	.499	.0543	−.166	.503	.0467	−.159	.662	.0375	−.187
10	.599	.0761	−.191	.600	.0605	−.168	.773	.0488	−.214
12	.695	.0972	−.223	.723	.0737	−.186	.830	.0673	−.217
14	.809	.121	−.238	.825	.0808	−.203	.803	.105	−.247
16	.929	.150	−.267	.842	.109	−.310	.771	---------	−.260
18	.964	.168	−.272	---------	---------	---------	---------	---------	---------

TABLE 23

R. A. F. 15 triplane. $G/c=1.2$. Stagger $=-30°$

	Upper wing			Middle wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M	C_L	C_D	C_M
Degrees									
−3	−0.049	+0.0137	−0.014	−0.061	+0.0125	−0.015	−0.089	+0.0164	−0.009
−2	+.002	.0127	−.026	−.009	.0131	−.040	−.015	.0153	−.032
−1	.079	.0123	−.060	+.069	.0135	−.058	+.073	.0142	−.060
0	.136	.0134	−.076	.135	.0142	−.085	.161	.0147	−.085
+1	.185	.0155	−.083	.189	.0159	−.086	.226	.0155	−.096
2	.235	.0180	−.094	.238	.0186	−.104	.294	.0160	−.104
3	.283	.0210	−.102	.291	.0214	−.109	.368	.0182	−.122
4	.340	.0258	−.125	.358	.0256	−.127	.436	.0211	−.141
6	.456	.0397	−.161	.466	.0363	−.150	.569	.0303	−.175
8	.561	.0565	−.175	.579	.0523	−.176	.692	.0399	−.201
10	.669	.0791	−.211	.690	.0677	−.200	.799	.0553	−.229
12	.769	.101	−.239	.798	.0822	−.231	.887	.0752	−.258
14	.878	.124	−.269	.899	.0977	−.253	.852	.112	−.275
16	.984	.149	−.285	.905	.127	−.268	.828	---------	−.297
18	1.01	.183	−.308	---------	---------	---------	---------	---------	---------

TABLE 24

R. A. F. 15 triplane. $G/c=0.6$. Stagger$=0°$

	Upper wing			Middle wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M	C_L	C_D	C_M
Degrees									
−3	−0.050	+0.0162	−0.008	+0.010	+0.0135	−0.031	+0.017	+0.0114	−0.045
−2	+.006	.0147	−.017	.058	.0140	−.047	.078	.0126	−.067
−1	.073	.0135	−.031	.093	.0145	−.059	.129	.0139	−.081
0	.134	.0141	−.060	.124	.0156	−.067	.178	.0163	−.093
+1	.185	.0145	−.071	.153	.0171	−.078	.221	.0197	−.104
2	.255	.0161	−.086	.200	.0187	−.086	.260	.0229	−.110
3	.310	.0183	−.097	.242	.0207	−.095	.312	.0266	−.124
4	.365	.0212	−.118	.278	.0231	−.100	.360	.0301	−.133
6	.478	.0286	−.145	.356	.0298	−.111	.446	.0401	−.155
8	.587	.0399	−.165	.425	.0382	−.122	.530	.0517	−.176
10	.700	.0539	−.193	.500	.0470	−.129	.610	.0632	−.192
12	.808	.0690	−.210	.565	.0545	−.143	.685	.0721	−.215
14	.917	.0859	−.237	.651	.0625	−.148	.740	.0869	−.217
16	.946	.116	−.254	.716	.0883	−.168	.780	.152	−.250
18	---------	---------	---------	.762	---------	−.293	.838	.232	---------

TABLE 25

R. A. F. 15 triplane. $G/c=0.8$. Stagger$=0°$

	Upper wing			Middle wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M	C_L	C_D	C_M
Degrees									
−3	−0.042	+0.0149	−0.009	−0.007	+0.0133	−0.026	−0.007	+0.0126	−0.031
−2	+.022	.0138	−.032	+.054	.0139	−.049	+.064	.0139	−.057
−1	.090	.0132	−.047	.098	.0144	−.056	.122	.0145	−.078
0	.156	.0142	−.068	.141	.0159	−.070	.175	.0161	−.095
+1	.209	.0149	−.086	.177	.0178	−.077	.221	.0196	−.109
2	.278	.0173	−.098	.224	.0195	−.085	.269	.0225	−.115
3	.338	.0197	−.117	.279	.0222	−.103	.324	.0255	−.126
4	.398	.0234	−.130	.323	.0251	−.111	.370	.0296	−.139
6	.513	.0325	−.161	.414	.0331	−.124	.469	.0390	−.155
8	.627	.0460	−.183	.497	.0431	−.147	.559	.0504	−.180
10	.756	.0612	−.204	.581	.0544	−.150	.650	.0624	−.198
12	.857	.0774	−.218	.666	.0646	−.169	.732	.0717	−.212
14	.980	.0981	−.245	.749	.0758	−.184	.785	.0891	−.220
16	1.01	1.33	−.268	.821	.112	−.213	.817	.157	−.267
18	1.01	---------	---------	.866	.184	−.250	.855	.230	---------

TABLE 26

R. A. F. 15 triplane. $G/c=1.0$. Stagger$=0°$

	Upper wing			Middle wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M	C_L	C_D	C_M
Degrees									
−3	−0.037	+0.0149	−0.010	−0.003	+0.0161	−0.034	−0.027	+0.0134	−0.023
−2	+.032	.0143	−.034	+.056	.0124	−.047	+.049	.0136	−.052
−1	.106	.0143	−.055	.109	.0129	−.061	.118	.0138	−.072
0	.173	.0159	−.082	.158	.0149	−.073	.167	.0157	−.091
+1	.225	.0176	−.086	.200	.0167	−.097	.219	.0183	−.098
2	.295	.0201	−.111	.248	.0186	−.094	.273	.0210	−.114
3	.354	.0228	−.131	.303	.0212	−.107	.331	.0239	−.123
4	.419	.0271	−.146	.352	.0248	−.117	.387	.0278	−.137
6	.546	.0374	−.165	.452	.0340	−.153	.492	.0373	−.156
8	.667	.0520	−.201	.550	.0462	−.158	.591	.0491	−.182
10	.787	.0678	−.225	.645	.0592	−.169	.682	.0613	−.206
12	---------	---------	---------	.732	.0707	−.200	.771	.0713	−.219
14	.997	.104	−.257	.828	.0854	−.209	.830	.0923	−.223
16	1.02	.142	−.307	.885	.128	−.244	.866	.154	−.271
18	1.01	---------	---------	.919	---------	---------	.892	.230	---------

TABLE 27

R. A. F. 15 triplane. $G/c=1.2$. Stagger=0°

	Upper wing			Middle wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M	C_L	C_D	C_M
Degrees									
−3	−0.003	+0.0145	−0.016	−0.007	+0.0136	−0.030	−0.036	+0.0152	−0.022
−2	+.034	.0129	−.038	+.068	.0133	−.051	+.035	.0150	−.046
−1	.107	.0125	−.061	.132	.0143	−.078	.108	.0156	−.066
0	.178	.0142	−.080	.181	.0161	−.095	.173	.0176	−.088
+1	.237	.0161	−.095	.225	.0189	−.109	.226	.0204	−.102
2	.306	.0179	−.117	.283	.0216	−.114	.283	.0230	−.113
3	.374	.0215	−.130	.341	.0248	−.132	.347	.0259	−.130
4	.441	.0256	−.138	.387	.0285	−.141	.402	.0298	−.140
6	.566	.0363	−.170	.500	.0378	−.159	.509	.0395	−.161
8	.693	.0511	−.208	.596	.0506	−.175	.617	.0512	−.187
10	.814	.0689	−.223	.702	.0643	−.201	.710	.0630	−.206
12	.934	.0872	−.247	.793	.0774	−.224	.799	.0732	−.232
14	1.03	.112	−.267	.883	.0952	−.244	.847	.0975	−.245
15	1.04	.134	−.282	---------	---------	---------	---------	---------	---------
16	1.05	.156	−.296	.922	.137	−.263	.868	.161	−.295
18	---------	---------	---------	.927	---------	---------	.886	.233	---------

TABLE 28

R. A. F. 15 triplane. $G/c=0.6$. Stagger=+15°

	Upper wing			Middle wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M	C_L	C_D	C_M
Degrees									
−4	---------	---------	---------	0.000	+0.0141	−0.033	---------	---------	---------
−3	−0.049	+0.0235	−0.006	+.049	.0139	−.047	+0.009	+0.0111	−0.042
−2	+.022	.0163	−.031	.097	.0147	−.065	.068	.0114	−.053
−1	.102	.0142	−.059	.133	.0156	−.067	.113	.0128	−.074
0	.161	.0122	−.066	.155	.0174	−.073	.158	.0142	−.084
+1	.232	.0120	−.085	.176	.0190	−.071	.194	.0168	−.092
2	.294	.0129	−.094	.228	.0208	−.087	.225	.0188	−.096
3	.356	.0164	−.104	.264	.0243	−.102	.270	.0221	−.110
4	.411	.0186	−.116	.303	.0278	−.104	.321	.0264	−.123
6	.542	.0274	−.147	.382	.0357	−.124	.407	.0384	−.145
8	.670	.0395	−.172	.458	.0461	−.136	.487	.0517	−.159
10	.797	.0550	−.197	.543	.0588	−.155	.570	.0690	−.180
12	.914	.0690	−.174	.622	.0671	−.171	.650	.0828	−.202
14	.975	.0923	−.236	.700	.0794	−.182	.715	.0948	−.218
16	.973	.130	−.250	.770	.102	−.199	.778	.119	−.244
18	.898	.165	−.256	.857	.154	−.240	.832	.186	−.278
20	---------	---------	---------	---------	---------	---------	.876	.262	−.320

TABLE 29

R. A. F. 15 triplane. $G/c=0.9$. Stagger=+15°

	Upper wing			Middle wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M	C_L	C_D	C_M
Degrees									
−3	−0.046	+0.0142	−0.012	+0.006	+0.0137	−0.028	−0.023	+0.0131	−0.021
−2	+.031	.0131	−.034	.068	.0134	−.058	+.045	.0124	−.038
−1	.116	.0121	−.059	.119	.0138	−.066	.103	.0129	−.060
0	.187	.0132	−.076	.158	.0166	−.076	.154	.0143	−.079
+1	.248	.0141	−.100	.197	.0183	−.084	.200	.0164	−.095
2	.323	.0151	−.110	.245	.0199	−.080	.239	.0182	−.097
3	.387	.0203	−.125	.298	.0235	−.106	.288	.0212	−.109
4	.456	.0232	−.139	.346	.0274	−.119	.344	.0248	−.120
6	.592	.0341	−.167	.444	.0371	−.142	.440	.0372	−.141
8	.728	.0488	−.203	.534	.0497	−.158	.530	.0508	−.168
10	.862	.0671	−.234	.634	.0653	−.183	.627	.0680	−.195
12	.982	.0843	−.258	.724	.0785	−.206	.718	.0813	−.210
14	1.06	.112	−.272	.817	.0932	−.224	.802	.0936	−.233
16	1.05	.160	−.306	.906	.154	−.328	.819	.124	−.238
18	---------	---------	---------	.957	.255	−.288	.865	.197	−.281

TABLE 30

R. A. F. 15 triplane. $G/c=1.2$. Stagger $=+15°$

	Upper wing			Middle wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M	C_L	C_D	C_M
Degrees									
−3	−0.057	+0.0146	−0.019	−0.003	+0.0139	−0.026	−0.043	+0.0143	−0.021
−2	+.016	.0133	−.045	+.045	.0130	−.046	+.031	.0141	−.045
−1	.105	.0121	−.066	.079	.0138	−.059	.102	.0141	−.066
0	.182	.0133	−.088	.164	.0163	−.083	.158	.0156	−.088
+1	.243	.0144	−.103	.209	.0183	−.092	.206	.0176	−.086
2	.323	.0158	−.123	.257	.0203	−.095	.260	.0199	−.102
3	.394	.0188	−.138	.321	.0240	−.115	.316	.0227	−.110
4	.465	.0232	−.156	.378	.0281	−.133	.374	.0270	−.126
6	.604	.0347	−.187	.486	.0390	−.157	.480	.0393	−.156
8	.746	.0500	−.224	.591	.0528	−.179	.587	.0537	−.179
10	.886	.0686	−.244	.701	.0699	−.210	.698	.0704	−.209
12	1.00	.0872	−.279	.800	.0848	−.233	.784	.0837	−.235
14	1.06	.117	−.298	.902	.104	−.252	.855	.0987	−.240
16	1.05	.170	−.333	.978	.144	−.277	.889	.134	−.263
18	----------	----------	----------	1.01	.229	−.336	.907	.215	−.318

TABLE 31

R. A. F. 15 triplane. $G/c=0.6$. Stagger $=+30°$

	Upper wing			Middle wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M	C_L	C_D	C_M
Degrees									
−3	−0.014	+0.0165	−0.016	+0.052	+0.0127	−0.042	−0.009	+0.0112	−0.029
−2	+.063	.0166	−.036	.097	.0121	−.048	+.042	.0099	−.044
−1	.151	.0147	−.058	.128	.0130	−.057	.079	.0102	−.057
0	.216	.0142	−.077	.158	.0146	−.061	.124	.0119	−.069
+1	.299	.0147	−.104	.189	.0166	−.064	.166	.0148	−.073
2	.370	.0158	−.107	.250	.0190	−.073	.201	.0181	−.079
3	.438	.0147	−.120	.279	.0226	−.084	.239	.0220	−.086
4	.500	.0195	−.133	.312	.0267	−.094	.287	.0269	−.107
6	.648	.0273	−.177	.394	.0371	−.109	.376	.0405	−.130
8	.790	.0400	−.198	.476	.0516	−.141	.453	.0540	−.150
10	.930	.0528	−.227	.555	.0643	−.143	.535	.0748	−.167
12	1.02	.0738	−.250	.643	.0785	−.165	.615	.0902	−.190
14	1.05	.120	−.265	.763	.0988	−.181	.700	.109	−.218
16	1.00	----------	−.295	.887	.131	−.210	.769	.130	−.228
18	----------	----------	----------	.955	.177	−.265	.844	.166	−.268

TABLE 32

R. A. F. 15 triplane. $G/c=0.9$. Stagger $=+30°$

	Upper wing			Middle wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M	C_L	C_D	C_M
Degrees									
−3	−0.023	+0.0152	−0.014	+0.009	+0.0124	−0.030	−0.002	+0.0124	−0.024
−2	+.063	.0150	−.053	.065	.0108	−.051	+.037	.0114	−.042
−1	.154	.0169	−.084	.120	.0109	−.060	.085	.0111	−.055
0	.227	.0143	−.089	.164	.0129	−.073	.133	.0127	−.067
+1	.305	.0148	−.106	.206	.0152	−.078	.181	.0155	−.075
2	.384	.0165	−.129	.257	.0177	−.092	.220	.0185	−.083
3	.458	.0192	−.143	.311	.0214	−.102	.268	.0219	−.097
4	.529	.0222	−.156	.360	.0265	−.111	.325	.0271	−.113
6	.674	.0313	−.192	.458	.0386	−.143	.418	.0396	−.140
8	.825	.0469	−.217	.560	.0549	−.170	.505	.0557	−.163
10	.962	.0634	−.256	.656	.0737	−.183	.596	.0710	−.180
12	1.07	.0862	−.281	.758	.0857	−.202	.667	.0846	−.197
14	1.12	.138	−.319	.879	.107	−.245	.755	.101	−.213
16	1.08	----------	−.357	.973	.141	−.262	.828	.124	−.230
18	----------	----------	----------	----------	----------	----------	.898	.165	−.260

TABLE 33

R. A. F. 15 triplane. $G/c=1.2$. Stagger $=+30°$

	Upper wing			Middle wing			Lower wing		
α	C_L	C_D	C_M	C_L	C_D	C_M	C_L	C_D	C_M
Degrees									
−3	−0.035	+0.0146	−0.016	−0.009	+0.0148	−0.022	−0.026	+0.0136	−0.019
−2	+.057	.0147	−.043	+.048	.0118	−.045	+.037	.0116	−.035
−1	.148	.0134	−.073	.109	.0115	−.060	.093	.0127	−.058
0	.216	.0140	−.095	.161	.0129	−.076	.153	.0151	−.080
+1	.290	.0149	−.099	.210	.0153	−.080	.204	.0183	−.092
2	.369	.0168	−.123	.264	.0177	−.093	.249	.0207	−.101
3	.449	.0201	−.143	.328	.0217	−.108	.310	.0231	−.111
4	.523	.0236	−.164	.382	.0264	−.123	.359	.0283	−.125
6	.682	.0343	−.194	.495	.0393	−.154	.463	.0410	−.152
8	.832	.0504	−.229	.605	.0557	−.191	.566	.0582	−.182
10	.970	.0671	−.270	.716	.0720	−.215	.665	.0740	−.210
12	1.08	.0879	−.283	.835	.0878	−.242	.752	.0884	−.221
14	1.12	.143	−.330	.953	.110	−.264	.858	.109	−.248
16	1.07	--------	--------	1.02	.152	−.284	.922	.136	−.247
18	--------	--------	--------	--------	--------	--------	.941	.198	−.287

TABLE 34.—R. A. F. 15 triplane.

Stagger $=-30°$

		C_{L_U}	C_{L_M}	C_{L_L}	$\frac{C_{L_U}}{C_{L_C}}$	$\frac{C_{L_M}}{C_{L_C}}$	$\frac{C_{L_L}}{C_{L_C}}$
$G/c=0.6$	90% $C_{L_C\,\max.}=0.688$	0.650	0.619	0.795	0.316	0.300	0.384
	50% $C_{L_C\,\max.}=.383$	.313	.339	.500	.272	.295	.433
	25% $C_{L_C\,\max.}=.191$	.138	.165	.272	.241	.288	.471
$G/c=0.9$	90% $C_{L_C\,\max.}=.765$	.720	.745	.831	.314	.324	.362
	50% $C_{L_C\,\max.}=.425$	.370	.384	.526	.290	.302	.408
	25% $C_{L_C\,\max.}=.212$	.184	.186	.270	.288	.292	.420
$G/c=1.2$	90% $C_{L_C\,\max.}=.819$	.768	.800	.888	.312	.326	.362
	50% $C_{L_C\,\max.}=.455$	.412	.428	.520	.302	.314	.384
	25% $C_{L_C\,\max.}=.228$	.208	.214	.258	.304	.313	.383

Stagger $=0°$

		C_{L_U}	C_{L_M}	C_{L_L}	$\frac{C_{L_U}}{C_{L_C}}$	$\frac{C_{L_M}}{C_{L_C}}$	$\frac{C_{L_L}}{C_{L_C}}$
$G/c=0.6$	90% $C_{L_C\,\max.}=0.755$	0.894	0.635	0.742	0.394	0.280	0.326
	50% $C_{L_C\,\max.}=.420$	.476	.350	.436	.378	.278	.344
	25% $C_{L_C\,\max.}=.210$	.216	.181	.240	.343	.288	.369
$G/c=0.8$	90% $C_{L_C\,\max.}=.825$	.955	.733	.778	.386	.296	.318
	50% $C_{L_C\,\max.}=.458$	.510	.406	.456	.371	.296	.333
	25% $C_{L_C\,\max.}=.229$	.240	.207	.240	.349	.302	.349
$G/c=1.0$	90% $C_{L_C\,\max.}=.852$	.956	.786	.805	.374	.308	.318
	50% $C_{L_C\,\max.}=.473$	.522	.436	.467	.368	.307	.325
	25% $C_{L_C\,\max.}=.237$	.253	.222	.239	.356	.312	.332
$G/c=1.2$	90% $C_{L_C\,\max.}=.864$	.958	.815	.812	.370	.314	.316
	50% $C_{L_C\,\max.}=.480$	.520	.454	.466	.361	.315	.324
	25% $C_{L_C\,\max.}=.240$	.252	.233	.232	.352	.324	.324

Stagger $=+15°$

		C_{L_U}	C_{L_M}	C_{L_L}	$\frac{C_{L_U}}{C_{L_C}}$	$\frac{C_{L_M}}{C_{L_C}}$	$\frac{C_{L_L}}{C_{L_C}}$
$G/c=0.6$	90% $C_{L_C\,\max.}=0.773$	0.957	0.670	0.692	0.413	0.289	0.298
	50% $C_{L_C\,\max.}=.430$	.528	.373	.394	.408	.288	.304
	25% $C_{L_C\,\max.}=.215$	.246	.199	.205	.380	.305	.315
$G/c=0.9$	90% $C_{L_C\,\max.}=.837$	1.01	.752	.745	.401	.300	.299
	50% $C_{L_C\,\max.}=.465$	.565	.424	.415	.405	.304	.291
	25% $C_{L_C\,\max.}=.232$	.273	.222	.211	.392	.319	.289
$G/c=1.2$	90% $C_{L_C\,\max.}=.883$	1.02	.818	.803	.387	.308	.305
	50% $C_{L_C\,\max.}=.490$	.568	.457	.448	.386	.311	.303
	25% $C_{L_C\,\max.}=.245$	.276	.235	.226	.376	.320	.304

Stagger = +30°

		C_{LU}	C_{LM}	C_{LL}	$\frac{C_{LU}}{C_{LC}}$	$\frac{C_{LM}}{C_{LC}}$	$\frac{C_{LL}}{C_{LC}}$
G/c=0.6	90% $C_{LC\ \max.}$=0.802	1.04	0.702	0.657	0.434	0.292	0.274
	50% $C_{LC\ \max.}$= .446	.613	.378	.353	.457	.282	.261
	25% $C_{LC\ \max.}$= .223	.296	.202	.170	.442	.302	.256
G/c=0.9	90% $C_{LC\ \max.}$= .865	1.09	.796	.698	.420	.305	.275
	50% $C_{LC\ \max.}$= .480	.624	.426	.383	.433	.296	.271
	25% $C_{LC\ \max.}$= .240	.312	.217	.186	.434	.302	.264
G/c=1.2	90% $C_{LC\ \max.}$= .908	1.09	.855	.775	.402	.314	.284
	50% $C_{LC\ \max.}$= .504	.623	.462	.429	.411	.306	.283
	25% $C_{LC\ \max.}$= .252	.310	.232	.212	.410	.307	.283

TABLE 35

Centers of pressure in per cent of chord on a R. A. F. 15 biplane

	Stagger −30°						Stagger 0°							
G/c	0.6		0.9		1.2		0.6		0.8		1.0		1.2	
α	Upper wing	Lower wing	Upper wing	Lower wing	Upper wing	Lower wing	Upper wing	Lower wing	Upper wing	Lower wing	Upper wing	Lower wing	Upper wing	Lower wing
Degrees														
−1	--------	--------	−76.3	−75.0	−63.1	−80.0	−70.2	−88.5	--------	--------	−87.3	--------	−86.5	−82.5
0	--------	−51.5	−61.0	−51.5	−55.5	−47.9	−42.0	−62.4	−65.1	−76.7	−55.0	−67.4	−52.8	−55.0
+1	--------	−44.8	−52.7	−45.2	−48.2	−41.8	−39.9	−50.0	−50.0	−59.9	−48.9	−57.0	−42.6	−46.3
2	--------	−40.5	−42.3	−40.0	−40.9	−37.6	−33.0	−50.2	−41.5	−53.6	−41.5	−49.6	−41.4	−40.7
3	−39.6	−37.4	−36.5	−35.9	−36.4	−36.0	−35.6	−44.5	−39.0	−47.6	−38.1	−41.2	−36.2	−37.4
4	−34.4	−34.1	−35.7	−34.7	−37.0	−33.4	−31.7	−41.5	−36.6	−40.0	−36.8	−39.3	−34.6	−35.7
6	−32.5	−31.9	−33.3	−30.7	−32.9	−30.4	−25.6	−34.2	−32.8	−36.4	−32.6	−35.2	−33.0	−32.9
8	−31.8	−30.4	−34.0	−28.6	−31.5	−30.0	−26.6	−33.2	−32.8	−34.5	−29.8	−32.8	−31.1	−30.8
10	−29.9	−27.6	−29.7	−28.2	−30.0	−27.4	−26.1	−30.9	−29.3	−33.9	−27.3	−31.0	−29.7	−28.4
12	−27.3	−28.0	−29.1	−29.2	−29.4	−28.4	−27.0	−30.6	−28.1	−31.4	−25.4	−30.1	−29.3	−28.9
14	−24.7	−31.7	−27.0	−31.2	−28.9	−31.9	−25.5	−31.1	−28.5	−32.0	−27.2	−31.0	--------	−30.1
16	−18.8	−33.3	−27.0	--------	−29.1	--------	−23.6	−34.5	−28.5	−34.7	−31.3	−33.1	--------	−33.5
18	--------	--------	−30.2	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------

TABLE 36

Centers of pressure in per cent of chord on a R. A. F. 15 biplane

	Stagger +15°						Stagger +30°					
G/c	0.6		0.9		1.2		0.6		0.9		1.2	
α	Upper wing	Lower wing	Upper wing	Lower wing	Upper wing	Lower wing	Upper wing	Lower wing	Upper wing	Lower wing	Upper wing	Lower wing
Degrees												
−1	−51.0	−56.9	−49.1	−63.0	−57.3	−54.9	−46.2	−52.5	−48.4	−67.8	−58.2	−68.9
0	−44.0	−50.5	−41.6	−46.2	−48.7	−50.0	−36.6	−55.2	−47.5	−48.4	−44.4	−52.6
+1	−35.0	−42.7	−39.5	−43.5	−42.2	−42.7	−34.9	−42.7	−36.0	−43.0	−38.2	−43.1
2	−37.0	−41.1	−32.1	−37.6	−36.7	−38.7	−31.8	−42.6	−37.5	−38.8	−37.3	−39.9
3	−30.4	−38.4	−31.8	−36.6	−32.9	−36.4	−29.6	−36.1	−33.0	−36.2	−32.7	−36.5
4	−28.7	−35.7	−29.5	−34.4	−31.0	−35.4	−28.8	−35.4	−31.6	−33.9	−33.0	−36.5
6	−27.4	−32.3	−27.8	−33.2	−28.8	−31.8	−27.6	−33.6	−30.7	−33.9	−30.2	−32.8
8	−26.8	−34.0	−26.4	−30.9	−28.3	−29.0	−26.5	−32.5	−29.8	−33.2	−29.4	−31.7
10	−25.6	−31.4	−25.5	−30.9	−26.9	−31.0	−25.8	−31.5	−26.1	−30.2	−23.9	−30.4
12	−23.9	−31.7	−26.0	−29.6	−27.6	−29.8	−23.0	−30.7	−24.3	−30.0	−24.1	−30.0
14	−25.6	−30.9	−26.3	−28.6	−28.8	−27.6	−29.0	−30.3	−29.0	−29.7	−30.8	−29.3
16	−27.2	−30.8	−28.8	−28.4	−32.1	−30.2	--------	−30.4	−33.1	−30.5	−33.3	−29.2

TABLE 37

Centers of pressure in per cent of chord on a U. S. A. T. S. 5 biplane of $G/c=0.9$

Stagger	−30°		0°		+30°	
α	Upper wing	Lower wing	Upper wing	Lower wing	Upper wing	Lower wing
Degrees						
−5	---------	−75.3	−65.8	−71.1	−53.6	−73.5
−3	−95.1	−56.4	−52.2	−55.2	−46.2	−56.1
−1	−74.2	−48.6	−44.1	−48.3	−42.7	−48.7
0	−65.9	−44.5	−40.9	−47.1	−38.9	−47.6
+1	−63.3	−41.6	−41.4	−44.6	−37.9	−46.5
2	−58.7	−41.3	−39.3	−43.6	−36.3	−43.8
3	−56.7	−37.6	−36.5	−41.3	−37.1	−42.4
4	−52.6	−37.3	−36.7	−40.1	−36.8	−40.9
6	−48.8	−35.7	−34.6	−37.0	−35.1	−38.9
8	−46.0	−34.8	−33.4	−36.0	−33.2	−37.8
10	−43.9	−33.2	−32.3	−35.1	−31.8	−36.0
12	−41.1	−31.8	−31.5	−34.1	−30.8	−35.6
14	−39.0	−32.1	−30.8	−32.6	−30.2	−34.6
16	−38.0	−32.5	−29.8	−32.6	−30.4	−34.1
18	−36.1	---------	---------	---------	−31.3	−34.0

TABLE 38

Centers of pressure in per cent of chord on R. A. F. 15 triplane

Stagger −30°									
G/c	0.6			0.9			1.2		
α	Upper wing	Middle wing	Lower wing	Upper wing	Middle wing	Lower wing	Upper wing	Middle wing	Lower wing
Degrees									
−2	---------	---------	---------	---------	---------	---------	---------	---------	---------
−1	---------	---------	−71.1	−77.4	---------	−82.9	−76.0	−84.0	−82.2
0	---------	---------	−57.8	−57.8	−64.7	−53.1	−55.9	−63.0	−52.9
+1	---------	---------	−47.4	−50.0	−53.5	−45.2	−44.9	−45.5	−42.5
2	---------	---------	−43.5	−41.8	−44.9	−38.4	−39.8	−43.5	−35.2
3	---------	---------	−38.4	−41.0	−38.2	−34.4	−35.9	−37.3	−33.0
4	−35.8	−35.3	−35.1	−36.2	−36.1	−30.6	−36.6	−35.4	−32.9
6	−34.2	−33.4	−30.3	−34.6	−32.2	−29.5	−35.2	−32.0	−30.7
8	−34.7	−31.7	−27.7	−33.1	−31.5	−28.5	−31.1	−30.3	−29.1
10	−36.4	−28.7	−29.1	−31.6	−27.9	−27.9	−31.4	−28.9	−28.7
12	−30.0	−27.4	−27.1	−31.8	−25.7	−26.2	−30.9	−29.0	−29.2
14	−29.7	−26.1	−30.8	−29.3	−24.8	−30.8	−30.6	−28.2	−32.3
16	−27.5	−23.3	−37.1	−28.3	−36.9	---------	−28.6	−29.6	---------
18	−28.6	---------	---------	−28.1	---------	---------	−27.6	---------	---------

TABLE 39

Centers of pressure in per cent of chord on R. A. F. 15 triplane

Stagger 0°												
G/c	0.6			0.8			1.0			1.2		
α	Upper wing	Middle wing	Lower wing	Upper wing	Middle wing	Lower wing	Upper wing	Middle wing	Lower wing	Upper wing	Middle wing	Lower wing
Degrees												
−2	−28.3	−81.0	−85.9	---------	−90.7	−89.0	---------	−84.0	---------	---------	−75.0	---------
−1	−42.5	−63.5	−62.8	−52.3	−57.2	−64.0	−51.8	−56.0	−61.0	−57.0	−59.1	−61.1
0	−44.8	−54.0	−52.2	−43.6	−49.6	−54.4	−47.4	−46.2	−54.5	−45.0	−52.5	−50.9
+1	−38.4	−51.0	−47.0	−41.2	−43.5	−49.3	−38.2	−48.5	−44.7	−40.1	−48.4	−45.1
2	−33.6	−42.8	−42.2	−35.1	−37.8	−42.6	−37.5	−37.8	−41.6	−38.1	−40.2	−39.8
3	−31.2	−39.1	−39.5	−34.5	−36.8	−38.8	−36.9	−35.2	−37.0	−34.6	−38.6	−37.3
4	−32.4	−35.9	−36.8	−32.7	−34.3	−37.5	−34.8	−33.2	−35.3	−31.2	−36.3	−34.7
6	−30.3	−31.1	−34.6	−31.4	−29.9	−33.0	−30.2	−33.7	−31.6	−30.0	−31.7	−31.5
8	−28.1	−28.6	−33.1	−29.2	−29.6	−32.1	−30.2	−28.7	−30.7	−30.0	−29.4	−30.2
10	−27.6	−25.7	−31.4	−27.1	−25.8	−30.5	−28.6	−26.2	−30.2	−28.6	−28.6	−29.0
12	−26.1	−25.4	−31.4	−25.5	−25.5	−29.0	---------	−27.4	−28.5	−26.5	−28.3	−28.9
14	−26.0	−22.9	−29.3	−25.2	−24.7	−28.2	−25.9	−25.4	−27.0	−26.0	−27.7	−28.5
16	−26.9	−23.6	−31.3	−26.5	−26.0	−32.1	−30.0	−27.5	−31.0	−27.0	−28.5	−32.9
18	---------	---------	---------	---------	−28.4	---------	---------	---------	---------	−28.1	---------	---------

TABLE 40

Centers of pressure in per cent of chord on R. A. F. 15 triplane

Stagger +15°									
G/c	0.6			0.9			1.2		
α	Upper wing	Middle wing	Lower wing	Upper wing	Middle wing	Lower wing	Upper wing	Middle wing	Lower wing
Degrees									
−2	----------	−67.0	−77.9	----------	−85.3	−88.3	----------	----------	----------
−1	−57.8	−50.4	−65.5	−50.8	−55.5	−58.3	−62.8	−74.7	−64.8
0	−41.0	−47.1	−53.2	−40.7	−48.1	−51.3	−48.4	−50.7	−56.3
+1	−36.6	−40.3	−47.5	−40.3	−42.6	−47.5	−42.4	−44.0	−46.5
2	−32.0	−38.0	−42.5	−34.1	−32.5	−40.4	−37.9	−36.8	−39.1
3	−29.2	−38.5	−40.6	−32.2	−35.5	−37.7	−34.9	−35.5	−34.6
4	−28.2	−34.2	−38.2	−30.5	−34.3	−34.9	−33.5	−35.1	−33.6
6	−27.1	−32.3	−35.5	−28.4	−31.8	−31.9	−31.0	−32.2	−32.3
8	−25.7	−29.6	−32.5	−27.9	−29.4	−31.6	−30.0	−30.2	−30.4
10	−24.8	−28.4	−31.4	−27.2	−28.8	−31.0	−27.6	−29.9	−29.9
12	−19.2	−27.4	−30.9	−26.4	−28.4	−29.2	−27.8	−29.2	−30.0
14	−24.4	−26.1	−30.4	−25.8	−27.5	−29.1	−28.1	−28.1	−28.1
16	−25.8	−25.9	−31.2	−29.0	−36.2	−29.0	−31.3	−28.4	−29.6
18	−28.2	−27.8	−33.1	----------	−29.0	−31.8	----------	−32.7	−34.2

TABLE 41

Centers of pressure in per cent of chord on R. A. F. 15 triplane

Stagger +30°									
G/c	0.6			0.9			1.2		
α	Upper wing	Middle wing	Lower wing	Upper wing	Middle wing	Lower wing	Upper wing	Middle wing	Lower wing
Degrees									
−2	−58.0	−49.5	----------	−85.5	−78.5	----------	−75.5	−93.8	−94.7
−1	−38.4	−44.5	−72.1	−54.5	−50.0	−64.7	−49.4	−55.0	−62.4
0	−35.6	−38.6	−55.6	−39.2	−44.5	−50.3	−44.0	−47.2	−52.3
+1	−34.7	−33.9	−44.0	−34.8	−37.9	−41.5	−34.2	−38.1	−45.1
2	−28.8	−29.1	−39.1	−33.5	−35.6	−37.6	−33.3	−35.1	−40.4
3	−27.3	−30.0	−35.8	−31.2	−32.7	−36.1	−31.8	−32.8	−35.7
4	−26.6	−29.4	−37.4	−29.4	−30.7	−34.6	−31.4	−32.1	−34.7
6	−27.3	−27.5	−34.4	−28.4	−31.4	−33.3	−28.4	−31.0	−32.7
8	−25.1	−29.5	−32.9	−26.4	−30.3	−32.0	−27.5	−31.4	−32.0
10	−24.6	−25.7	−31.1	−26.7	−27.8	−30.1	−28.0	−30.0	−31.5
12	−24.6	−25.5	−30.6	−26.4	−26.6	−29.4	−26.3	−29.0	−29.4
14	−28.0	−25.0	−30.9	−28.6	−27.9	−28.1	−29.5	−27.8	−28.9
16	----------	−23.7	−29.0	----------	−27.0	−27.7	----------	−27.8	−26.7
18	----------	−24.9	−31.3	----------	----------	−28.7	----------	----------	−30.1

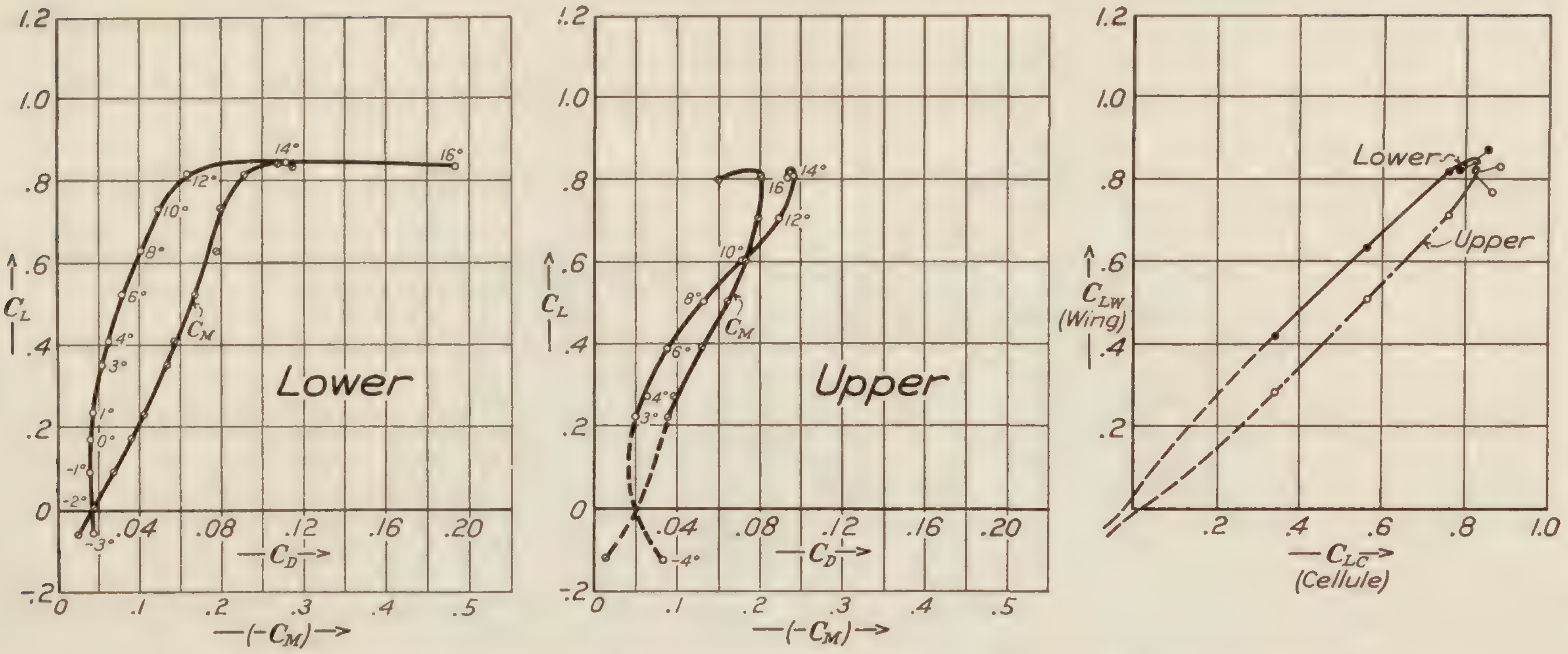


FIG. 3.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 biplane. $G/c=0.6$; Stagger −30°

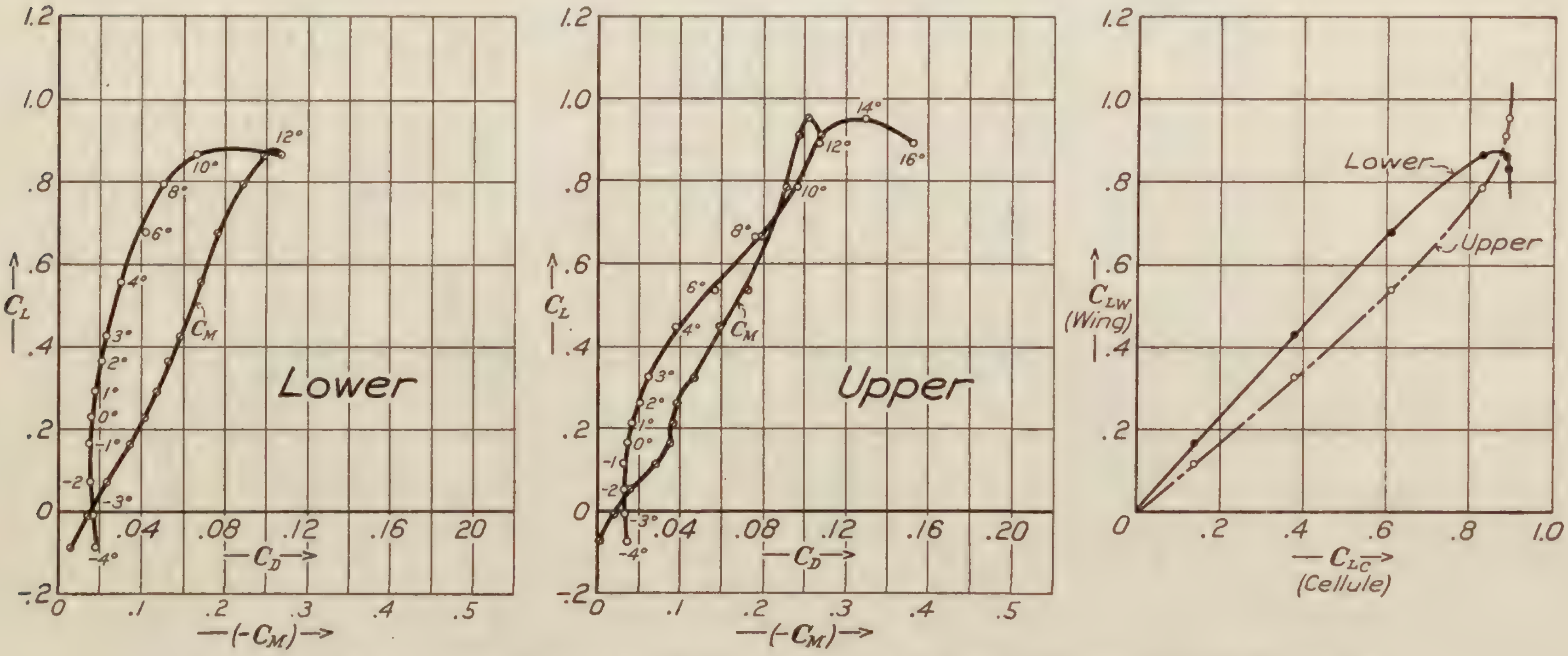


FIG. 4.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 biplane. $G/c=0.9$; Stagger −30°

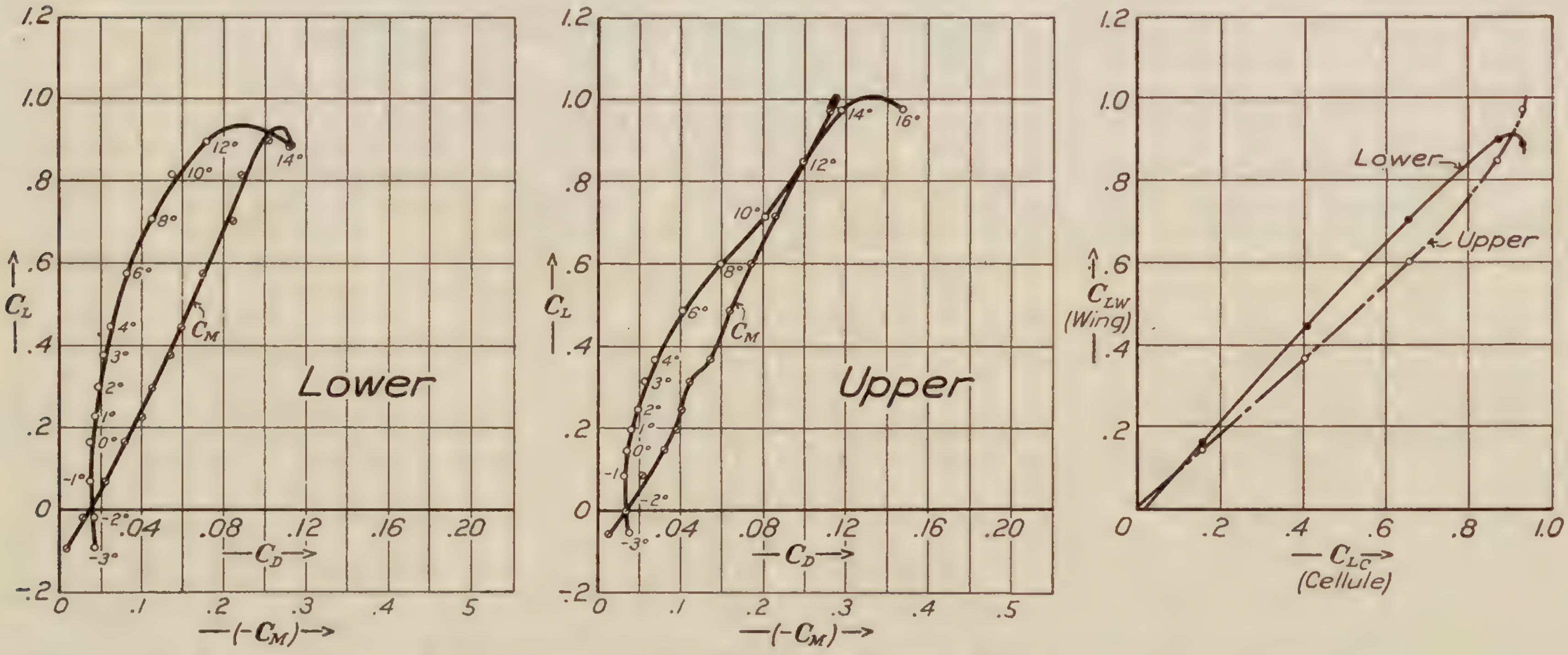


FIG. 5.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 biplane. $G/c=1.2$; Stagger −30°

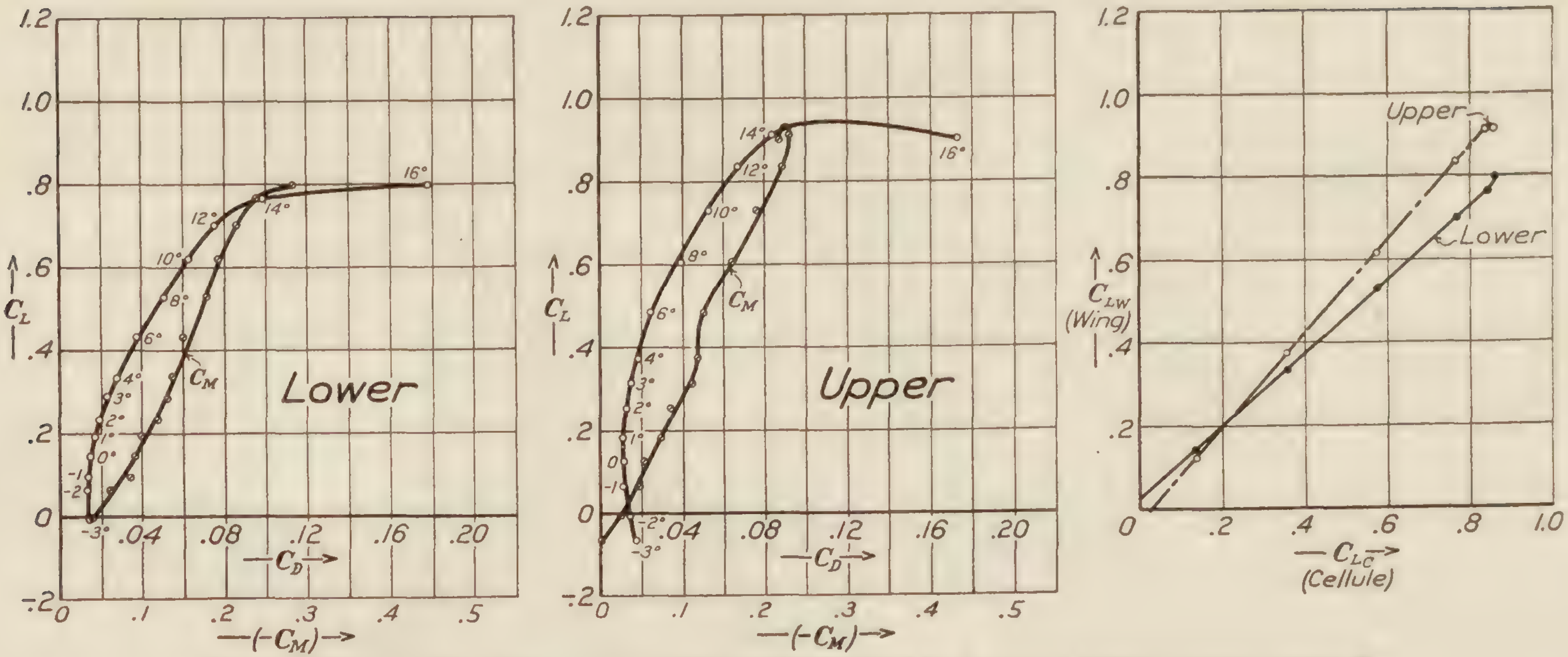


FIG. 6.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 biplane. $G/c=0.6$; Stagger 0°

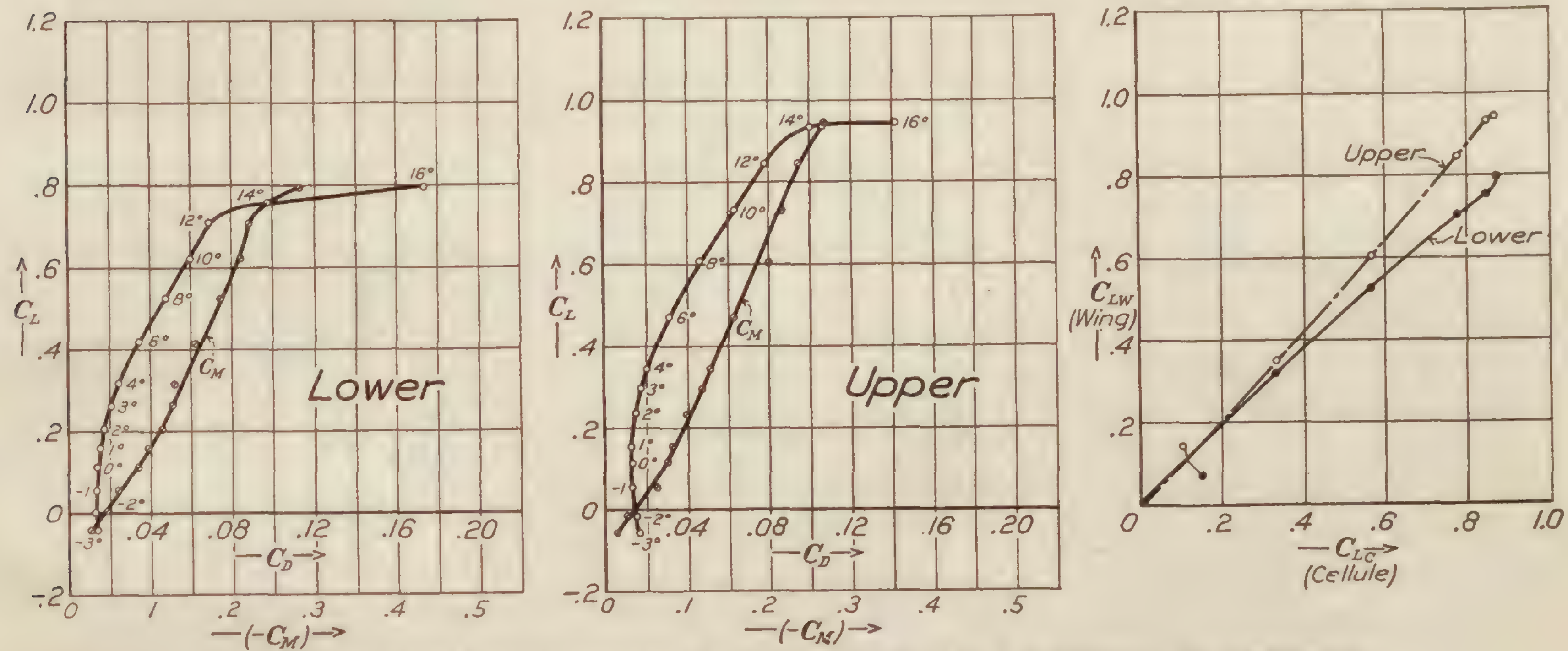


FIG. 7.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 biplane. $G/c=0.8$; Stagger 0°

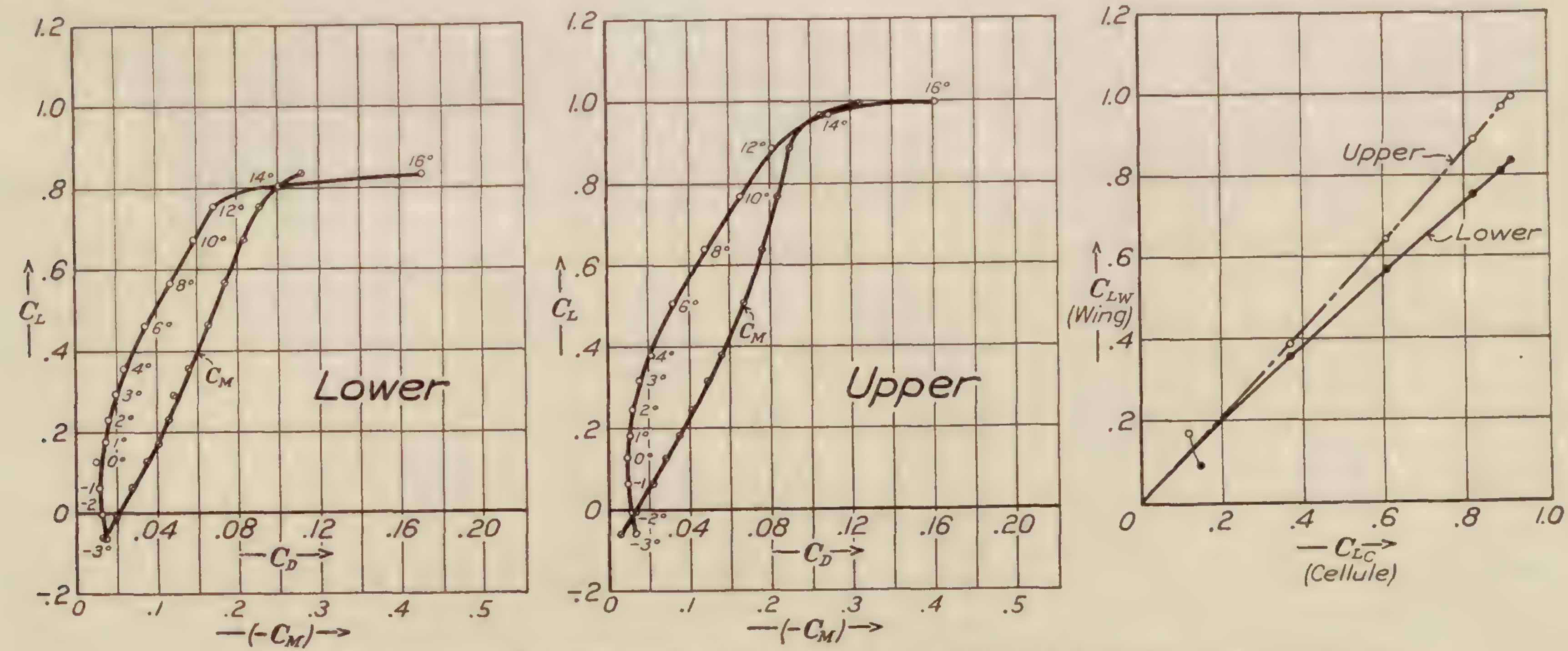


FIG. 8.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 biplane. $G/c=1.0$; Stagger 0°

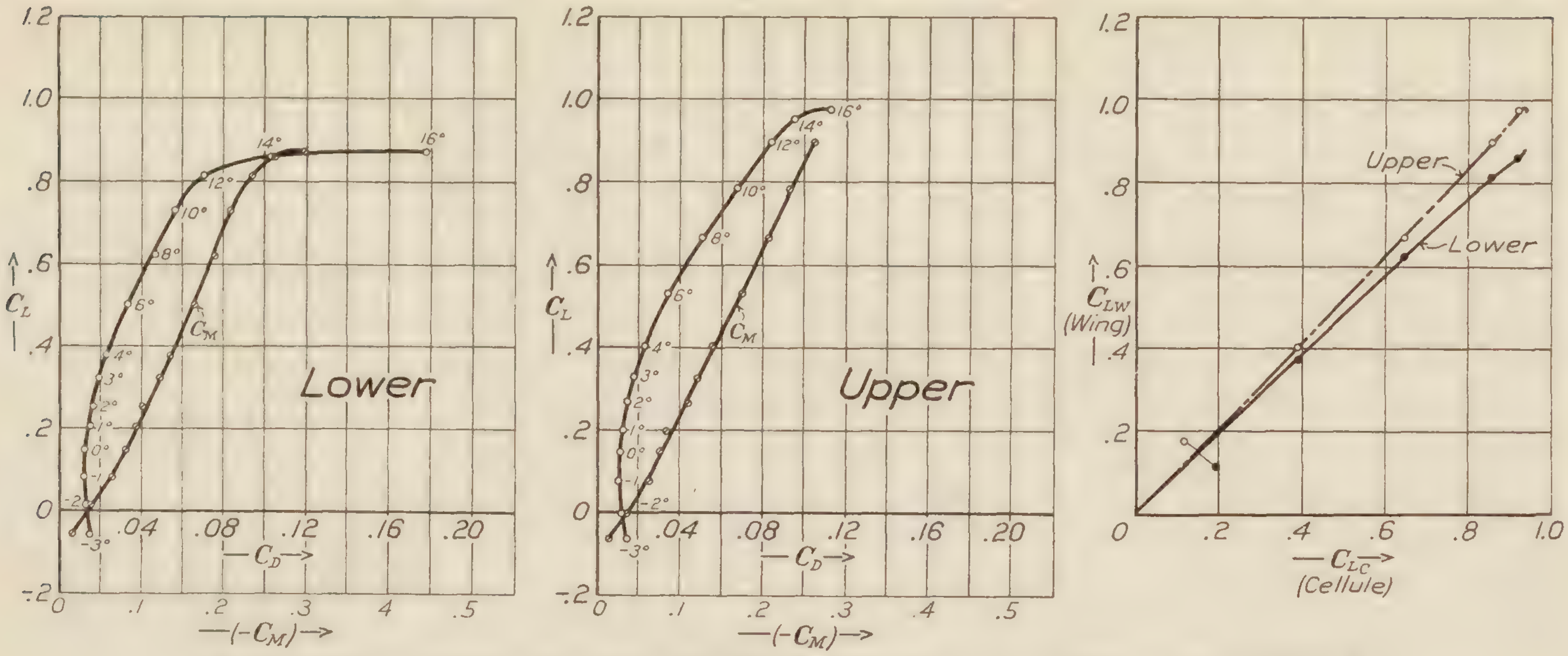


FIG. 9.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 biplane. *G/c*=1.2; Stagger 0°

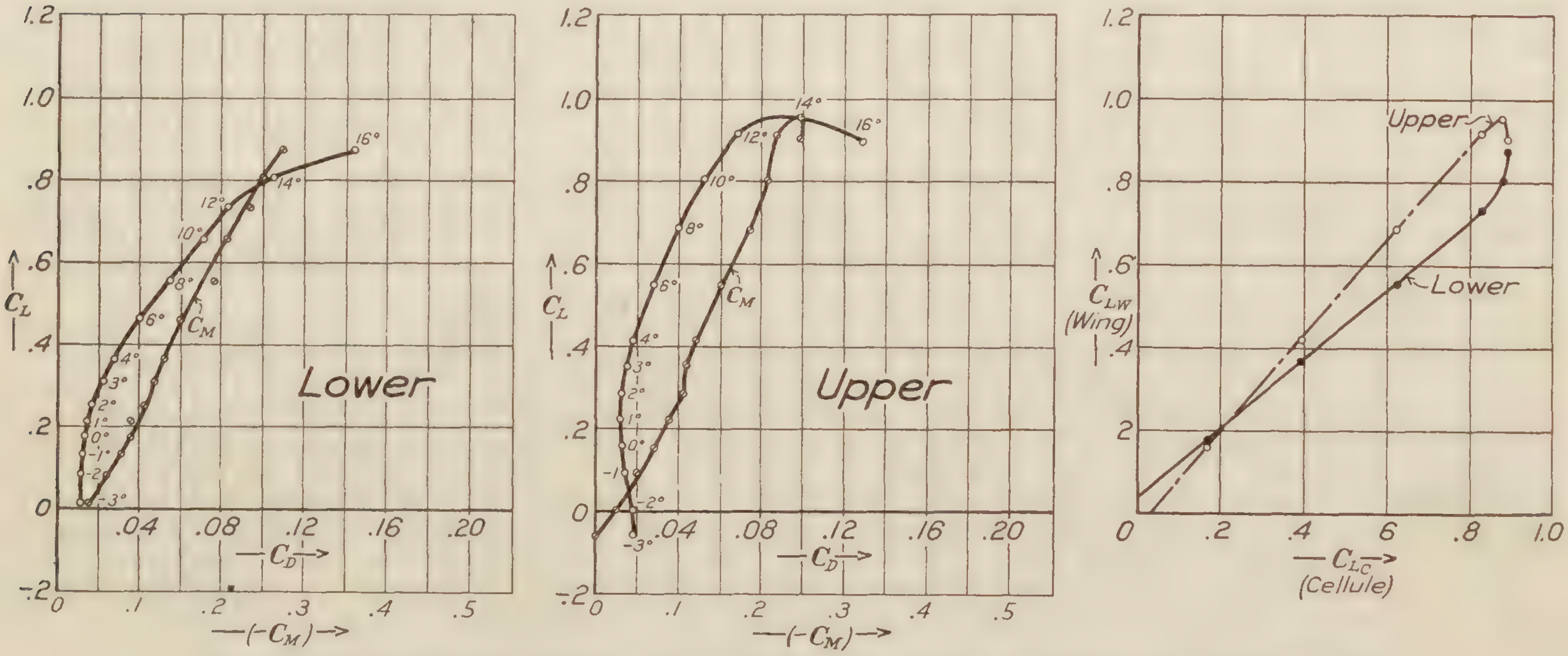


FIG. 10.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 biplane. *G/c*=0.6; Stagger +15°

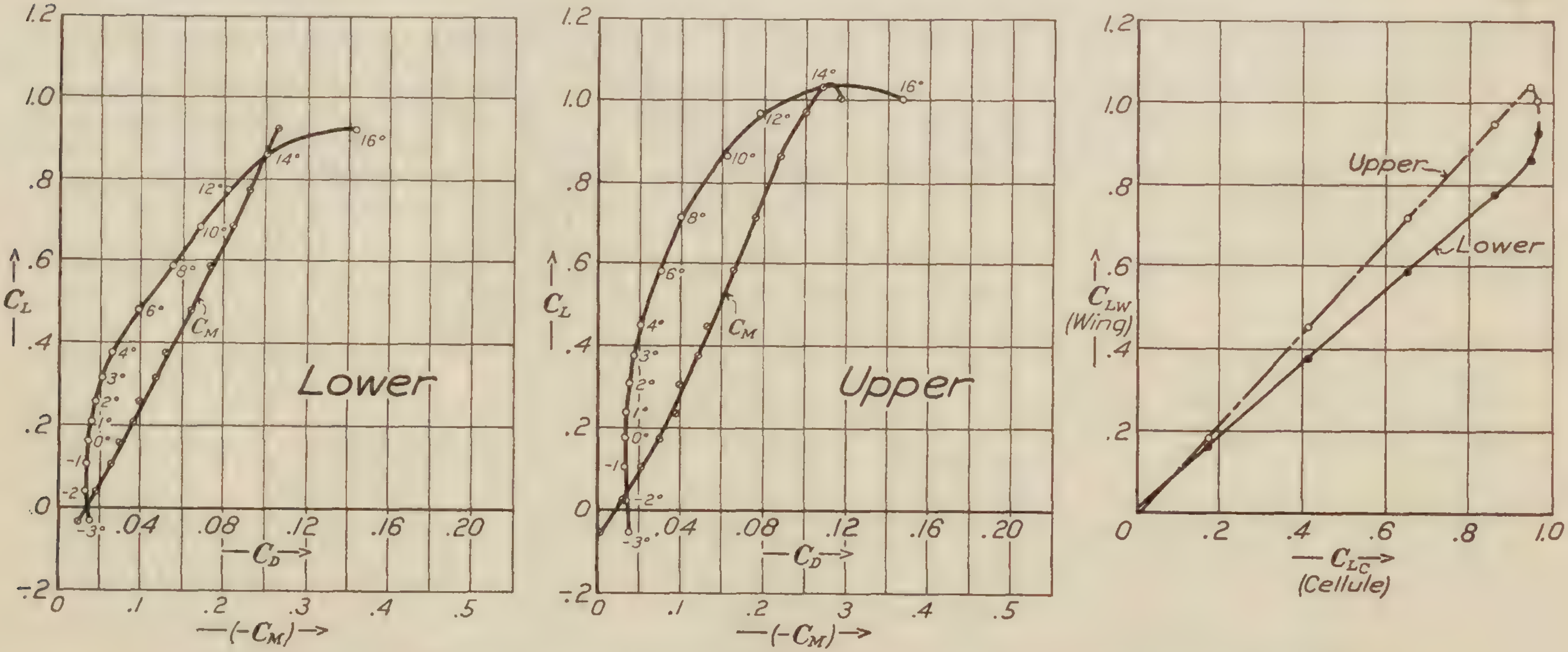


FIG. 11.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 biplane. *G/c*=0.9; Stagger +15°

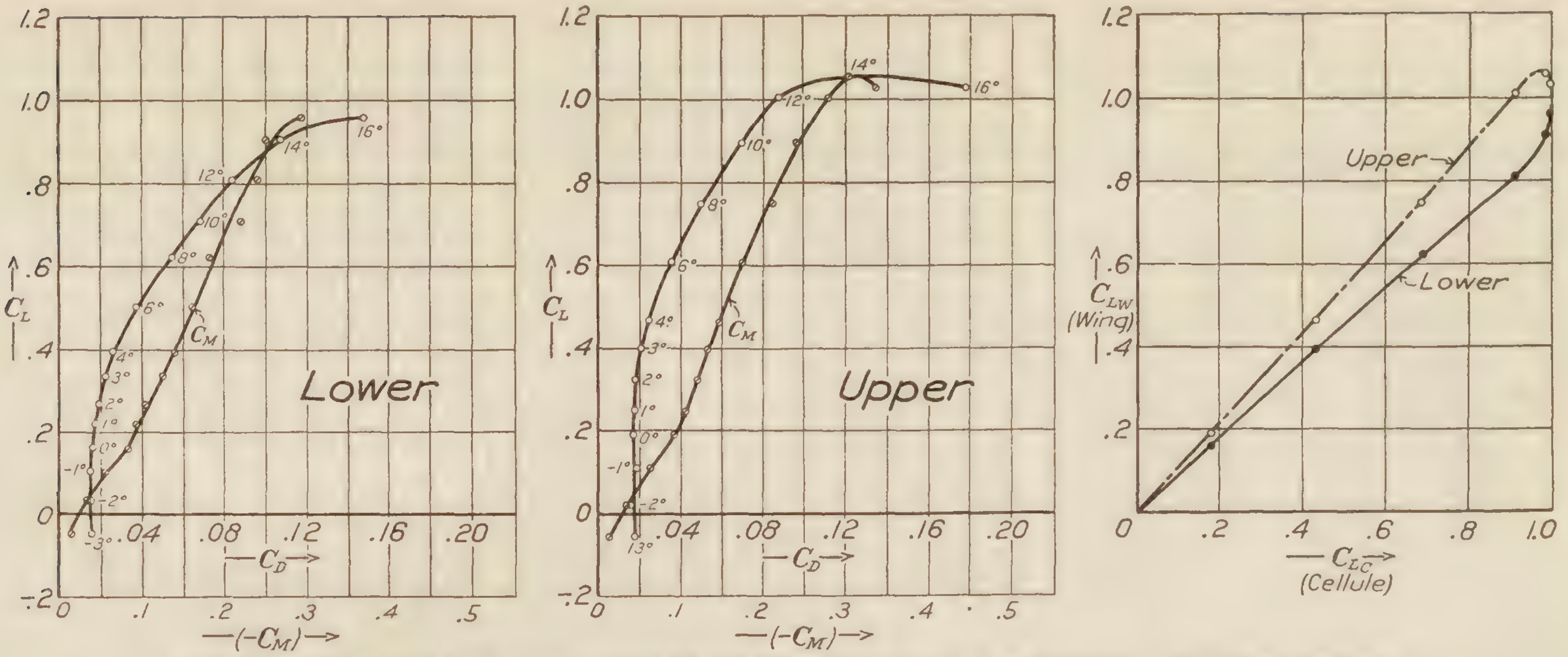


FIG. 12.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 biplane. $G/c=1.2$; Stagger +15°

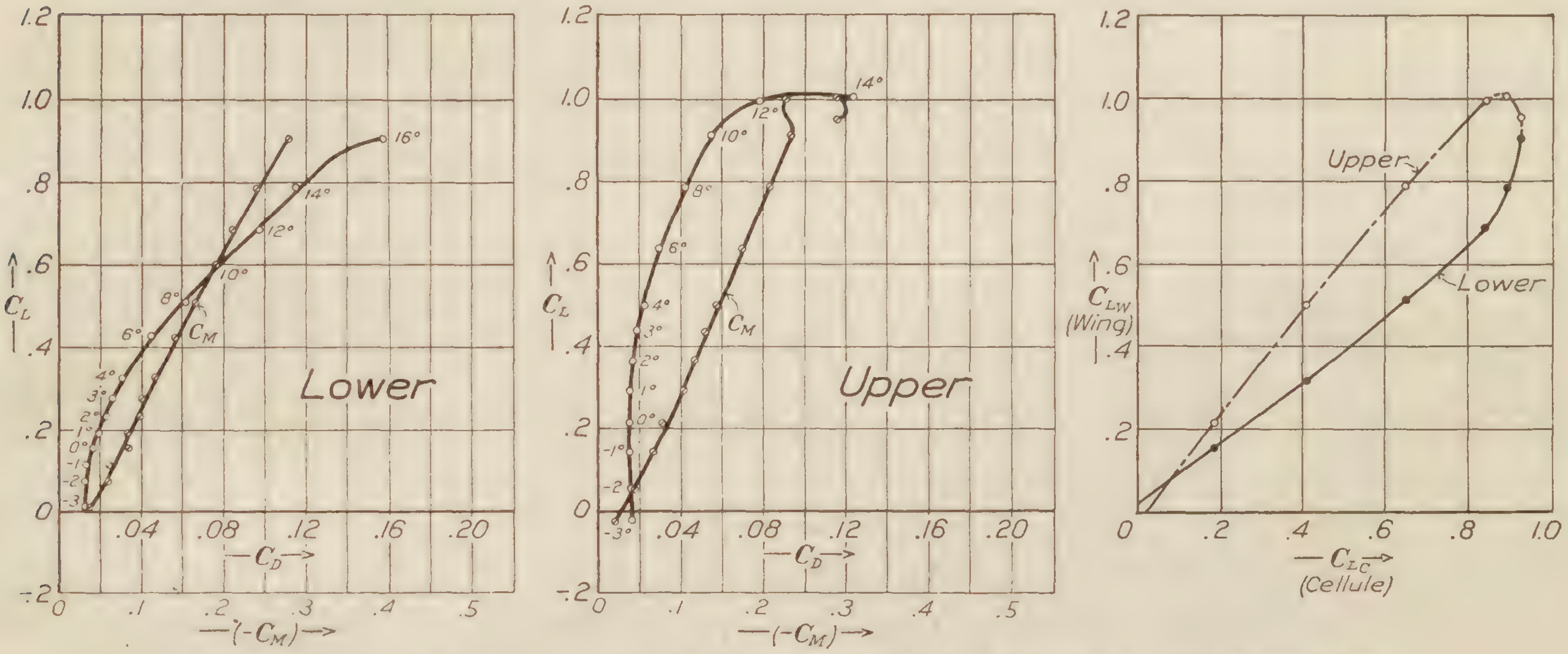


FIG. 13.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 biplane. $G/c=0.6$; Stagger +30°

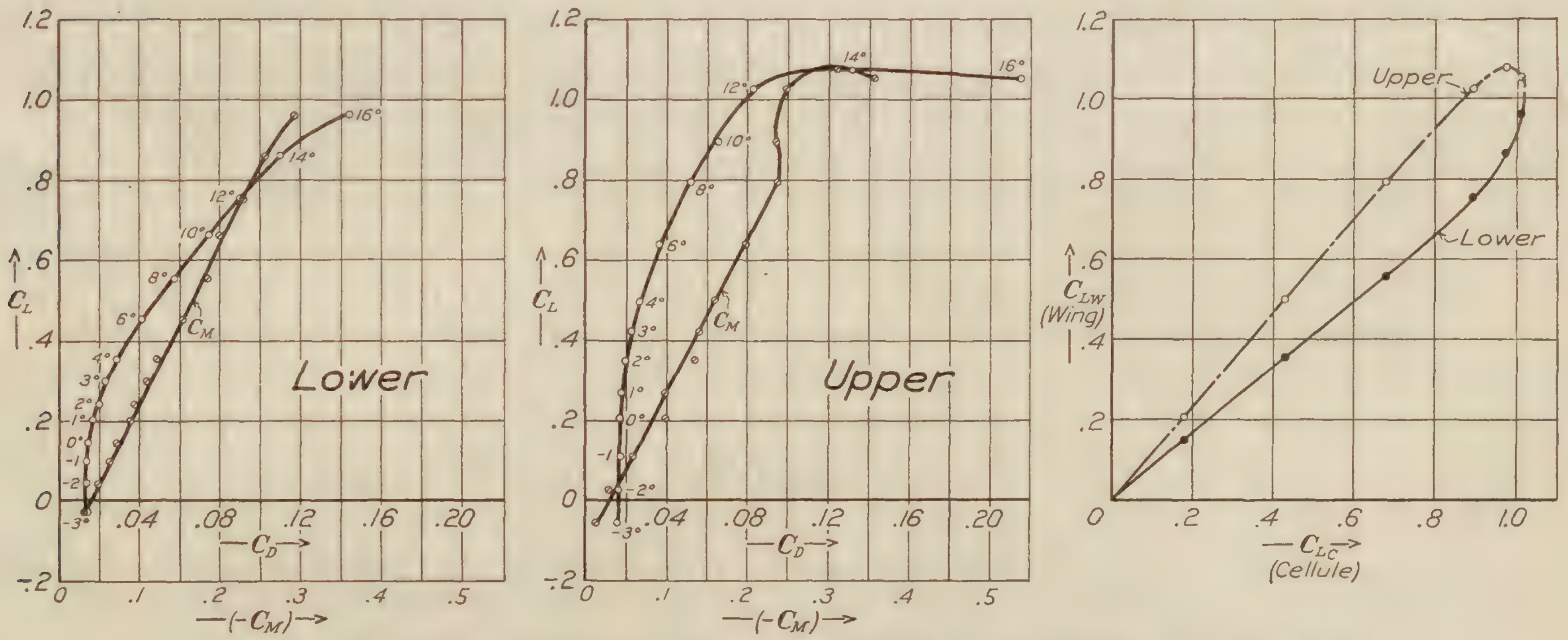


FIG. 14.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 biplane. $G/c=0.9$; Stagger +30°

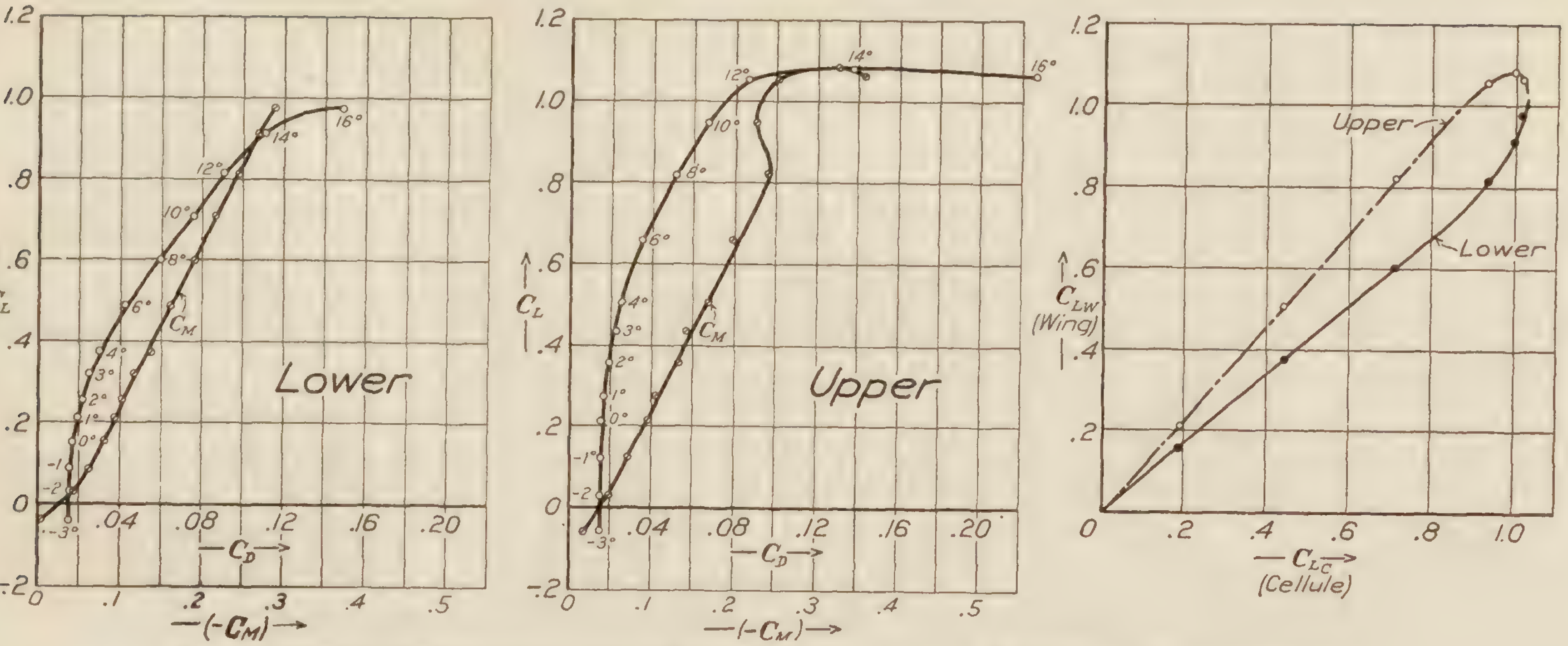


FIG. 15.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 biplane. $G/c=1.2$; Stagger +30°

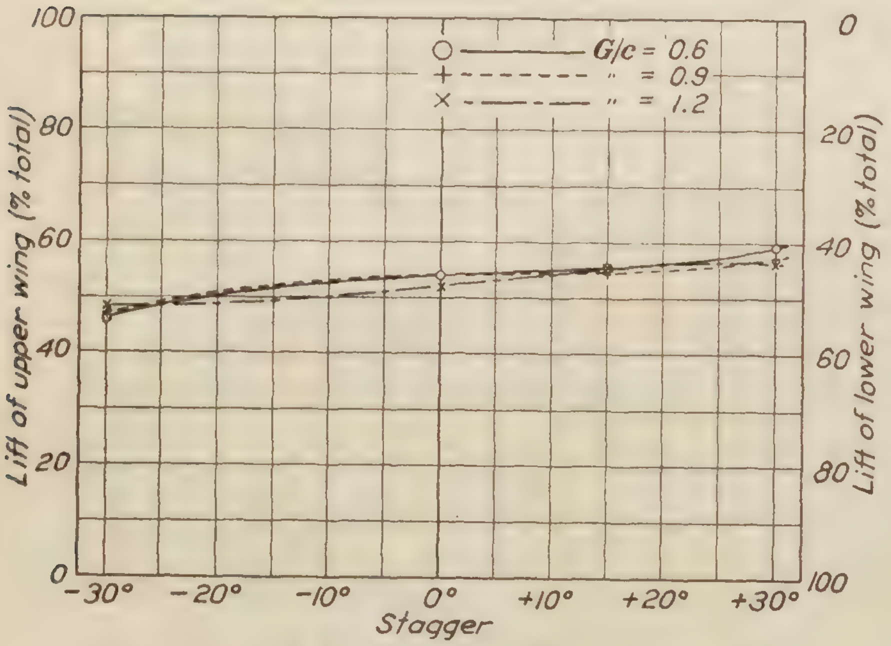


FIG. 16.—R. A. F. 15 biplane relative lift at 0.9 maximum lift

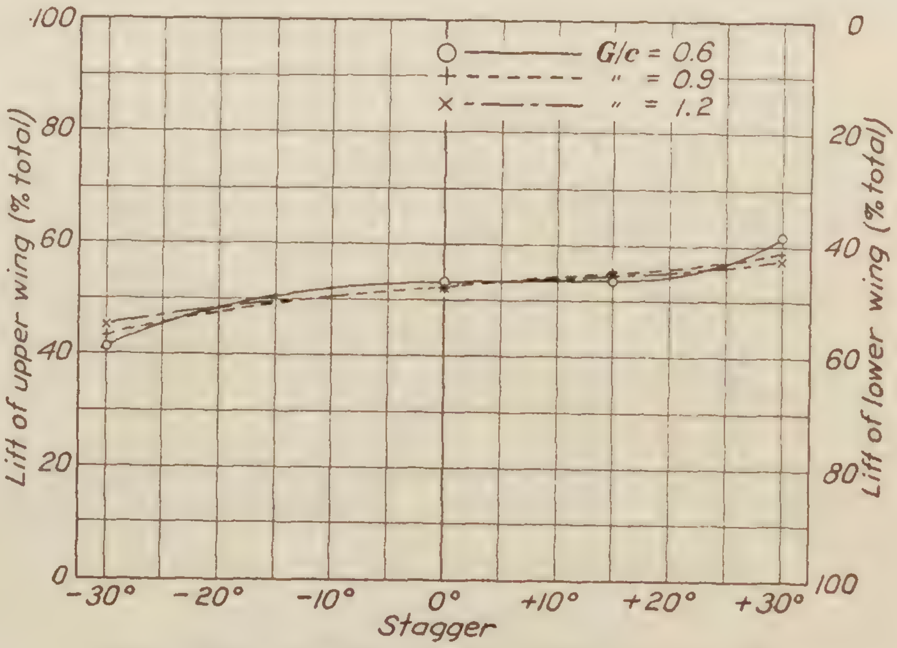


FIG. 17.—R. A. F. 15 biplane relative lift at 0.5 maximum lift

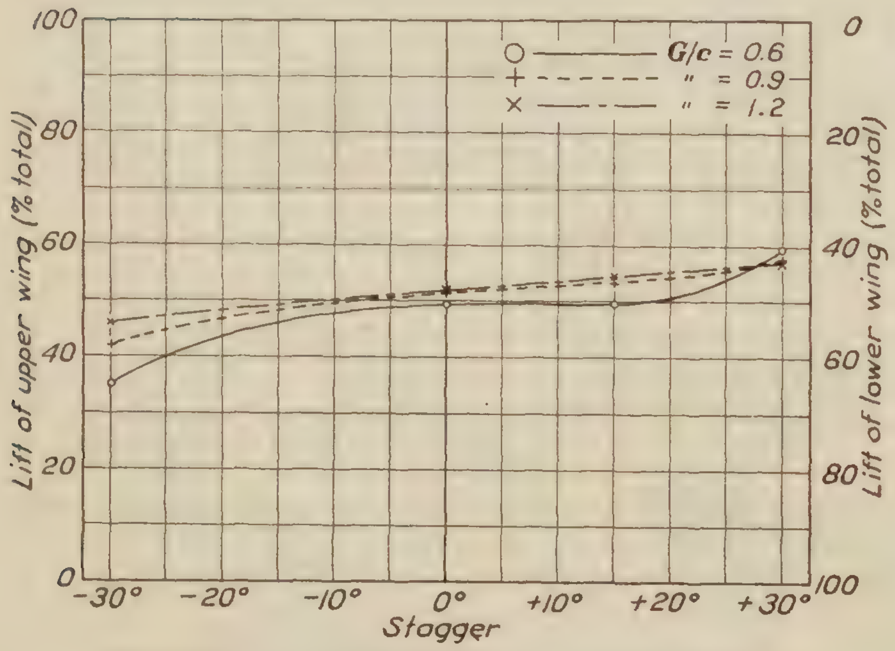


FIG. 18.—R. A. F. 15 biplane relative lift at 0.25 maximum lift

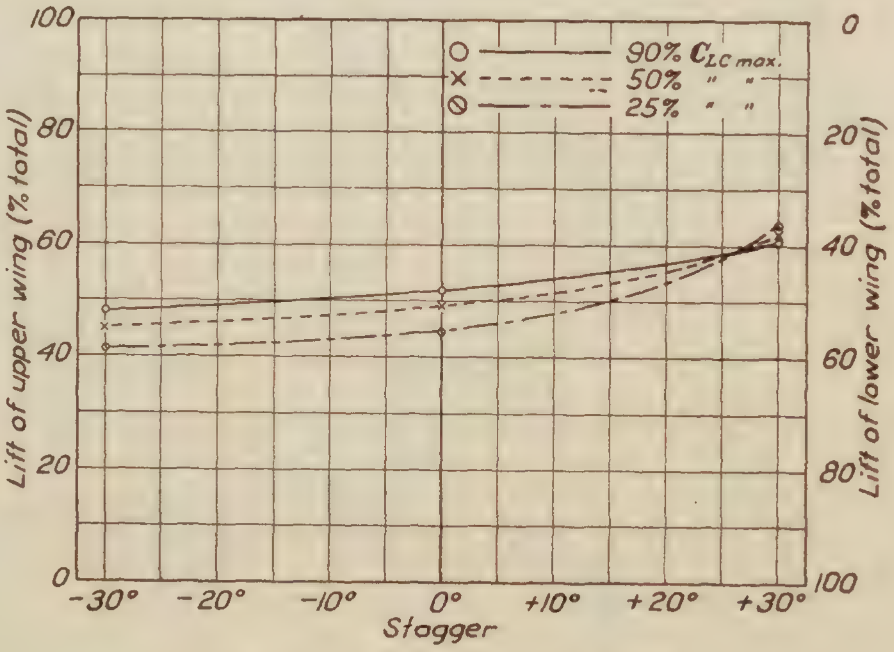


FIG. 22.—U. S. A. T. S. 5 biplane. $G/c=0.9$

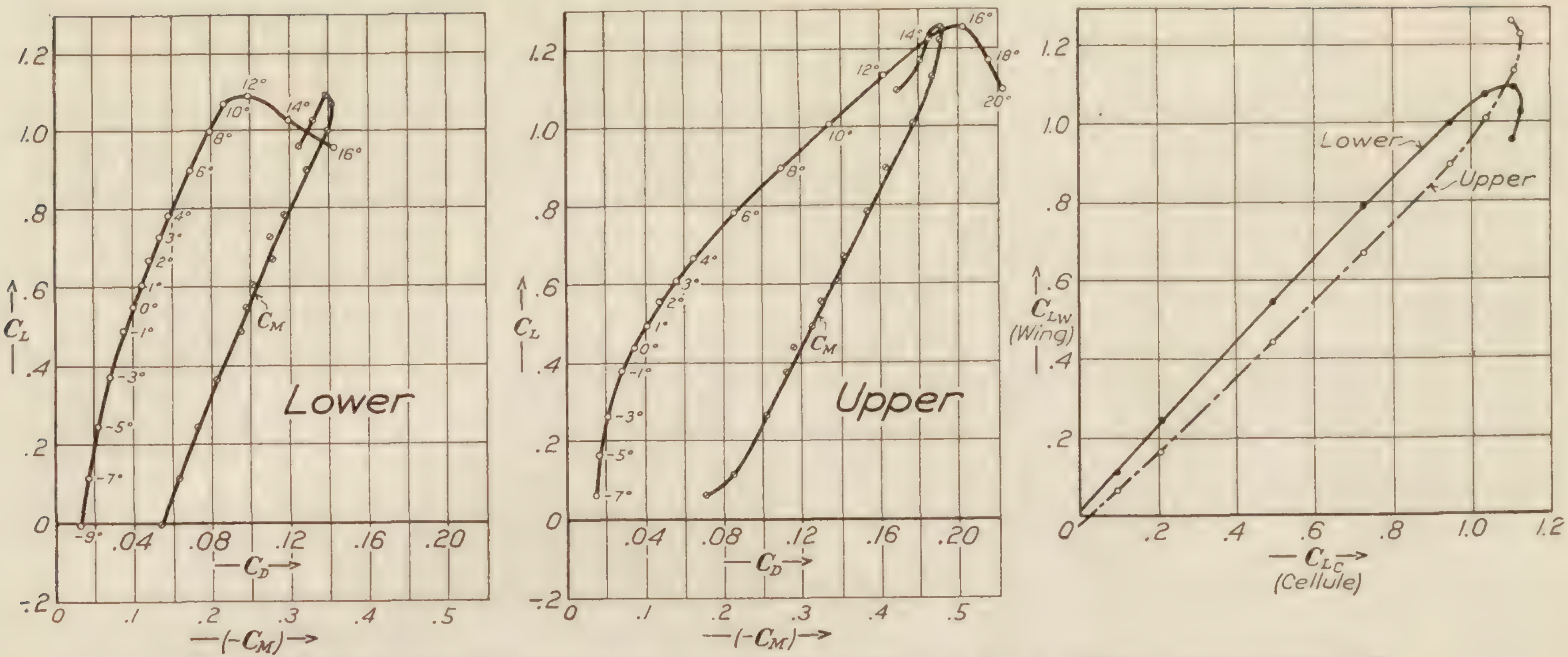


FIG. 19.—Curves of coefficients of moments and lift of individual wings for U. S. A. T. S. 5 biplane. $G/c=0.9$; Stagger $-30°$

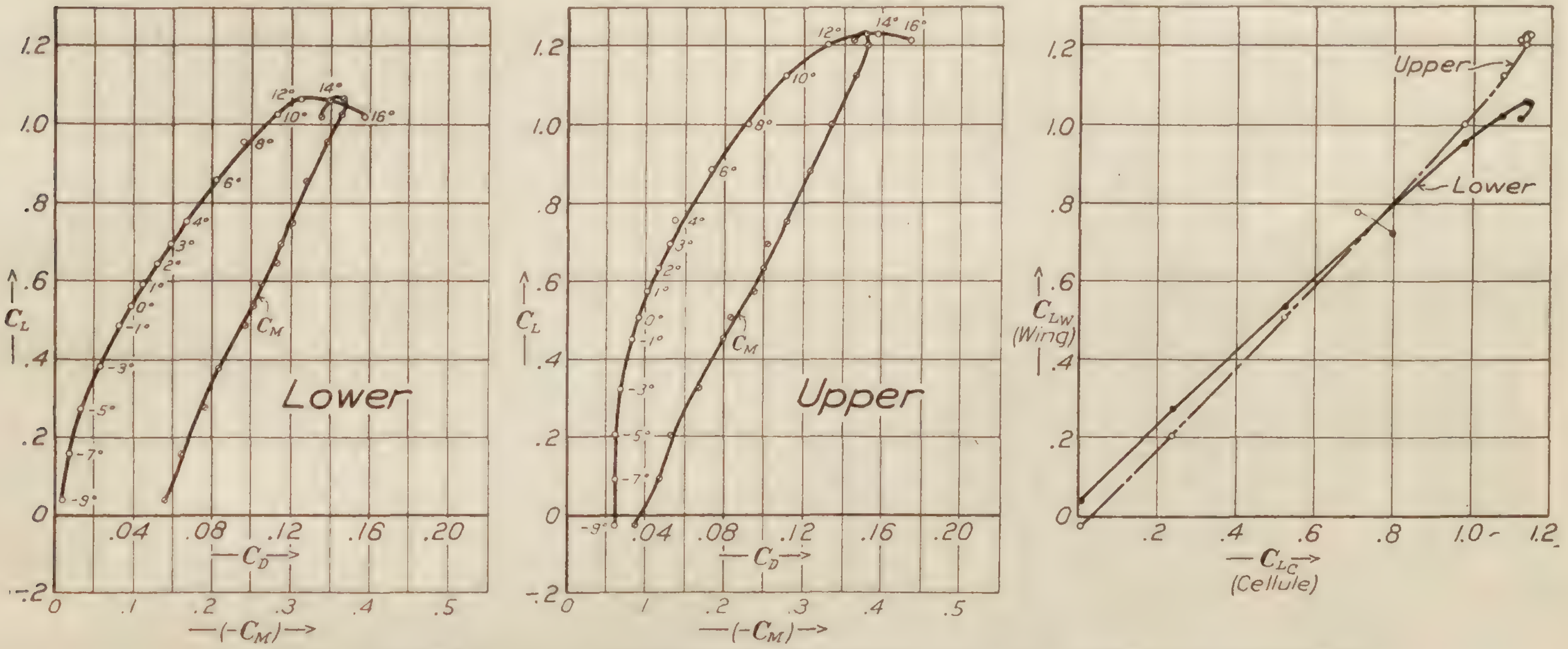


FIG. 20.—Curves of coefficients of moments and lift of individual wings for U. S. A. T. S. 5 biplane. $G/c=0.9$; Stagger 0°

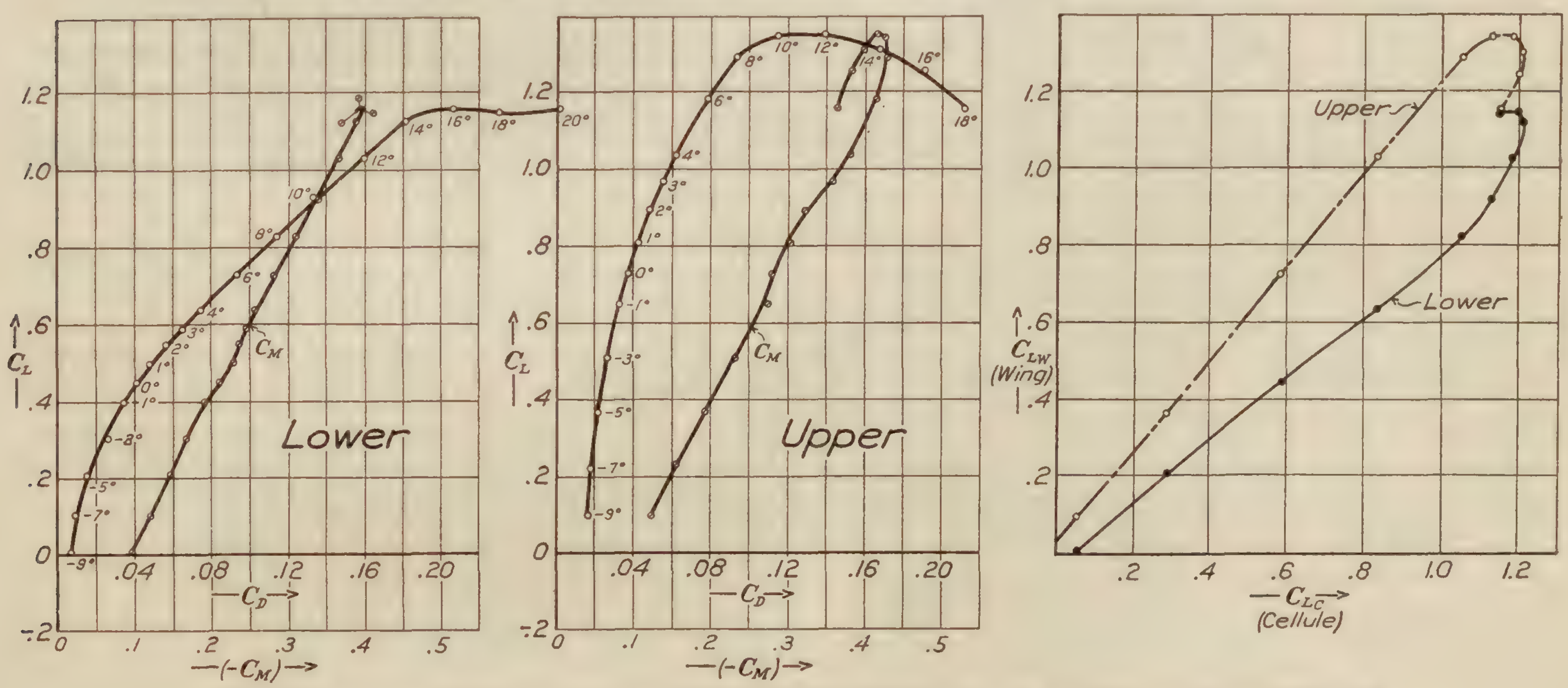


FIG. 21.—Curves of coefficients of moments and lift of individual wings for U. S. A. T. S. 5 biplane. $G/c=0.9$; Stagger $+30°$

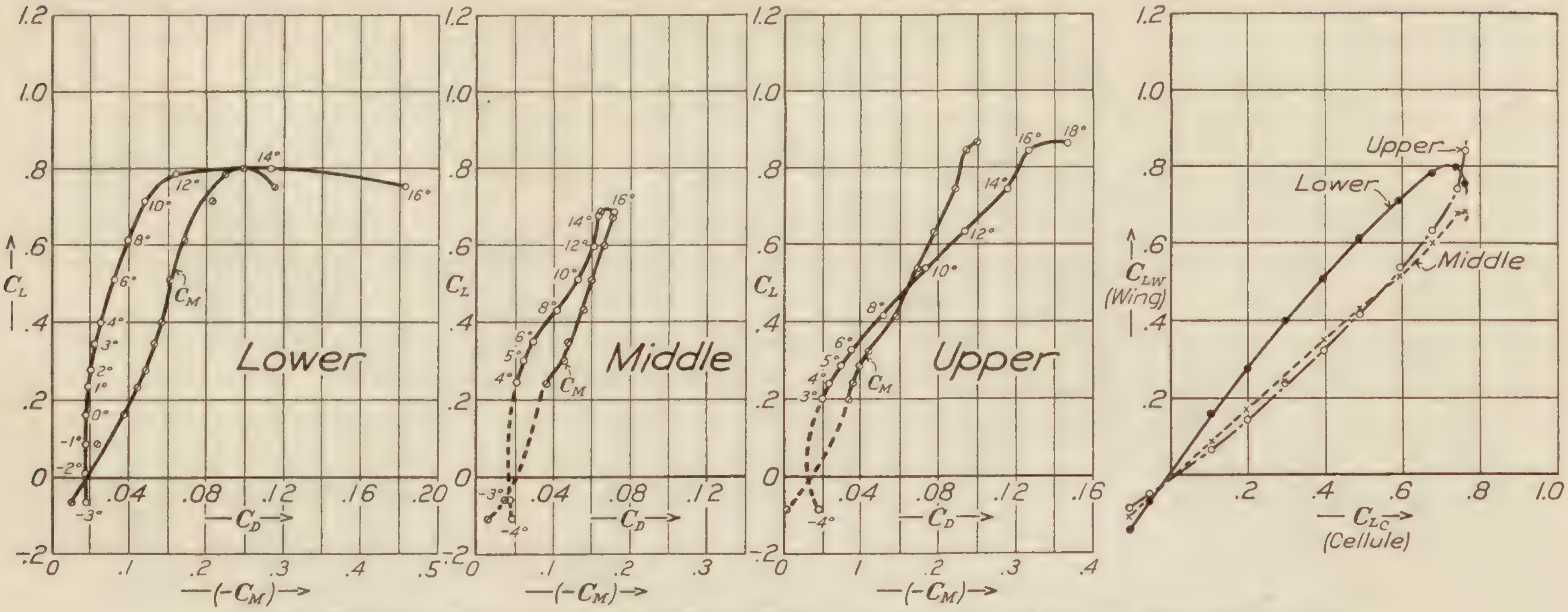


FIG. 23.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 triplane. $G/c=0.6$; Stagger −30°

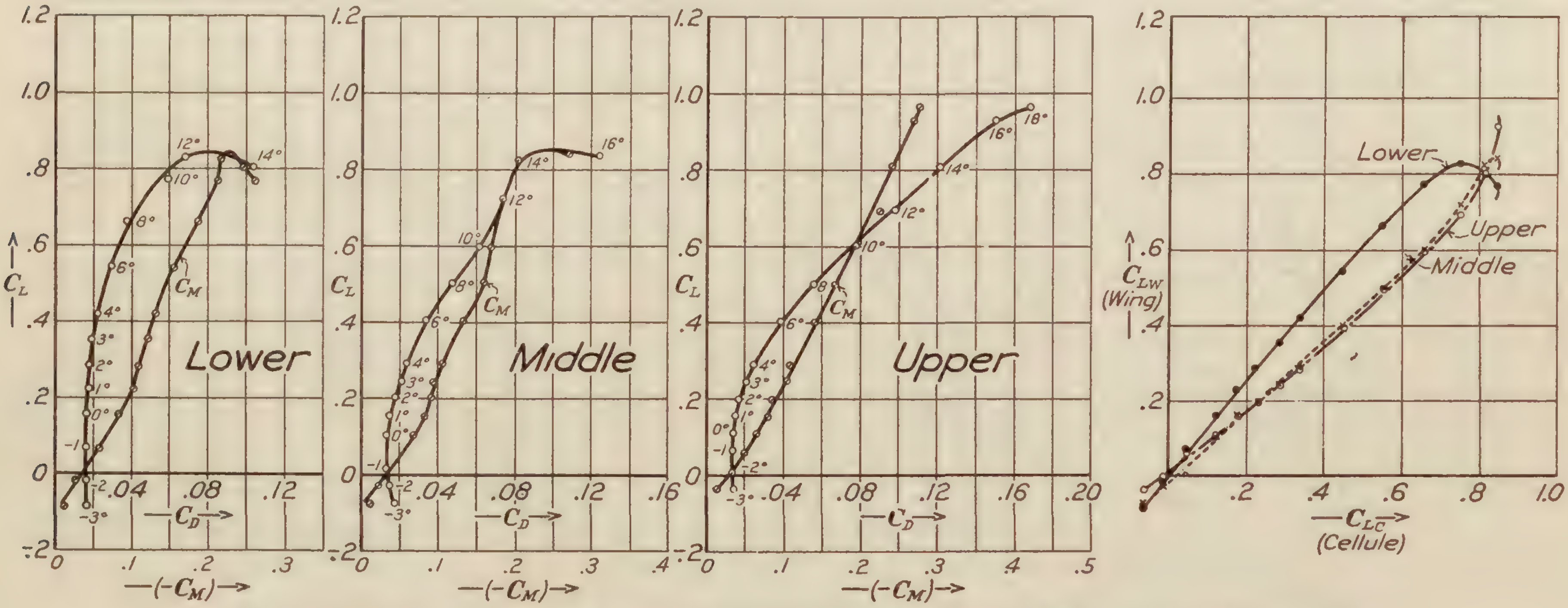


FIG. 24.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 triplane $G/c=0.9$; Stagger −30°

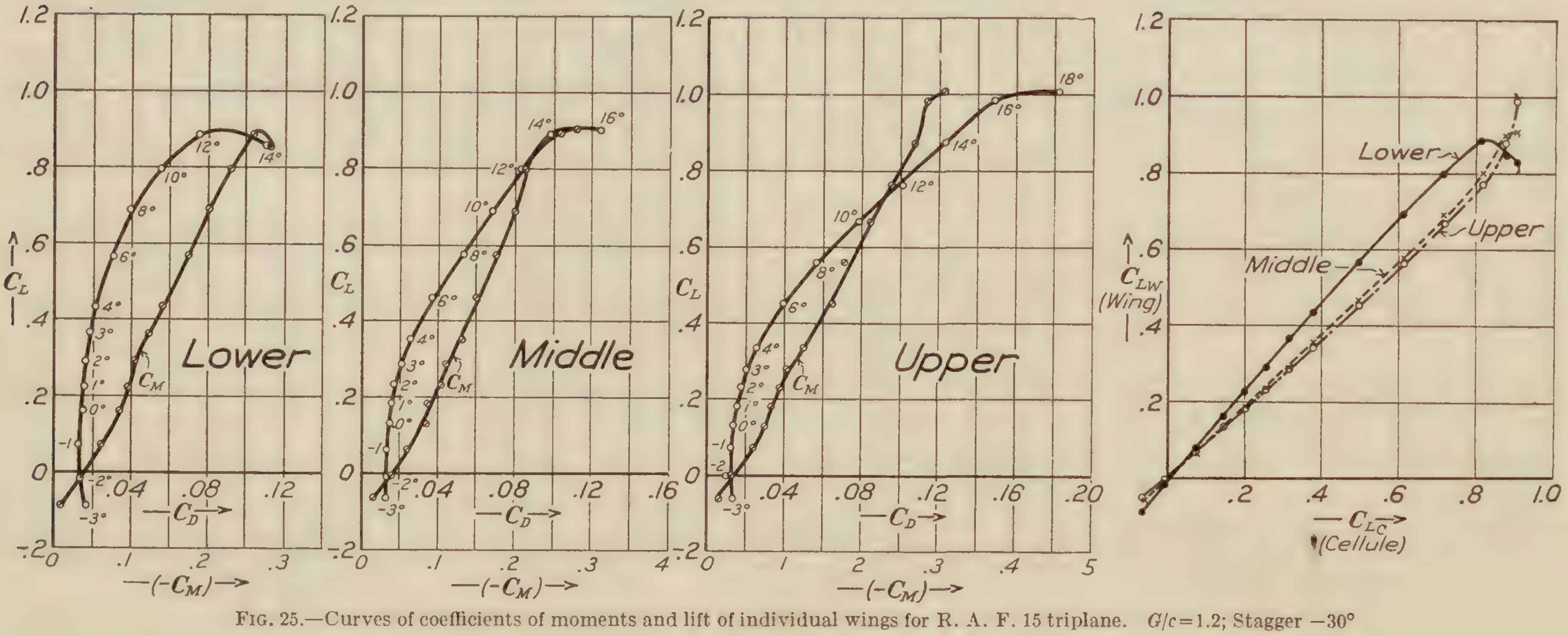


FIG. 25.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 triplane. $G/c=1.2$; Stagger −30°

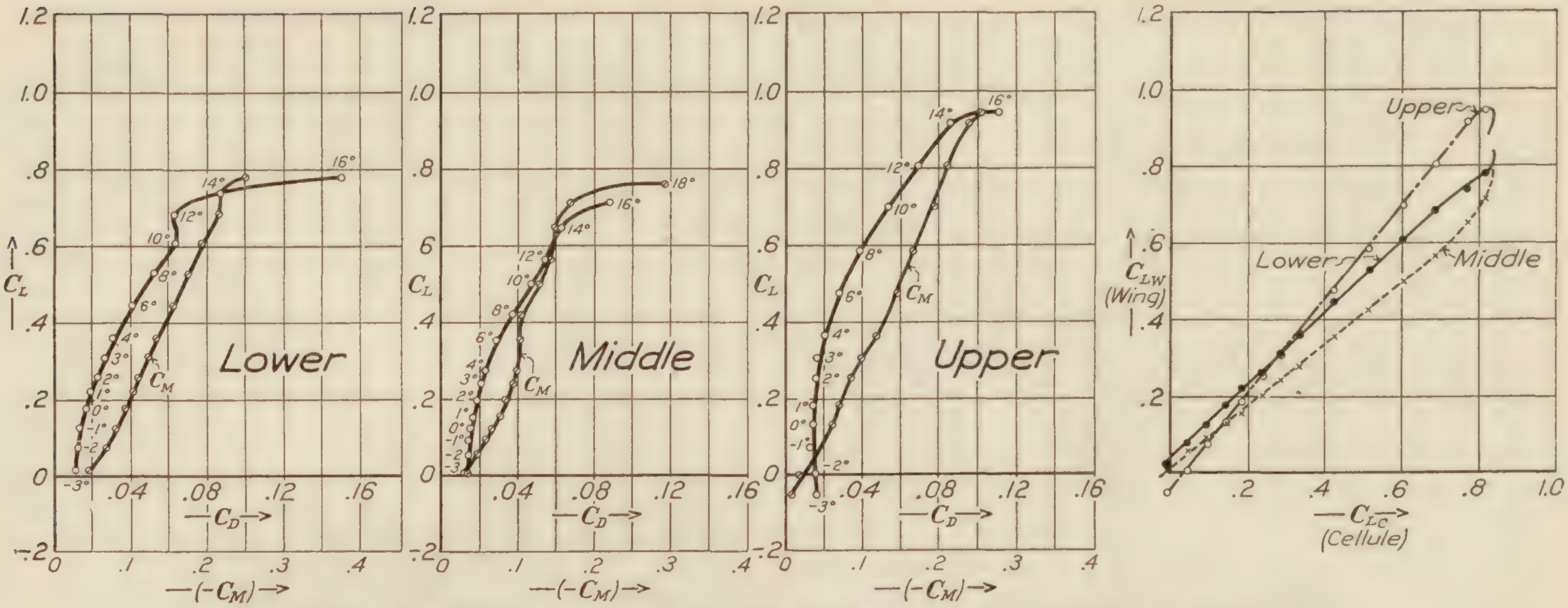


FIG. 26.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 triplane. $G/c=0.6$; Stagger 0°

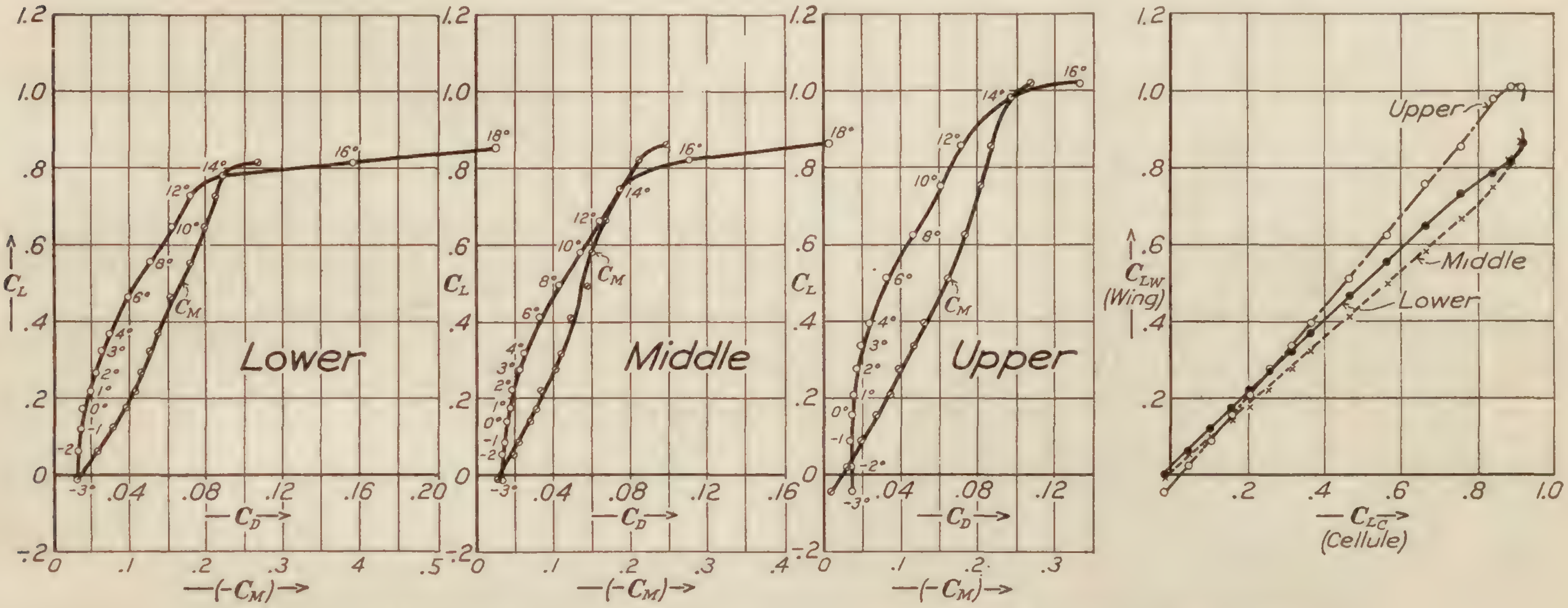


FIG. 27.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 triplane. $G/c=0.8$; Stagger 0°

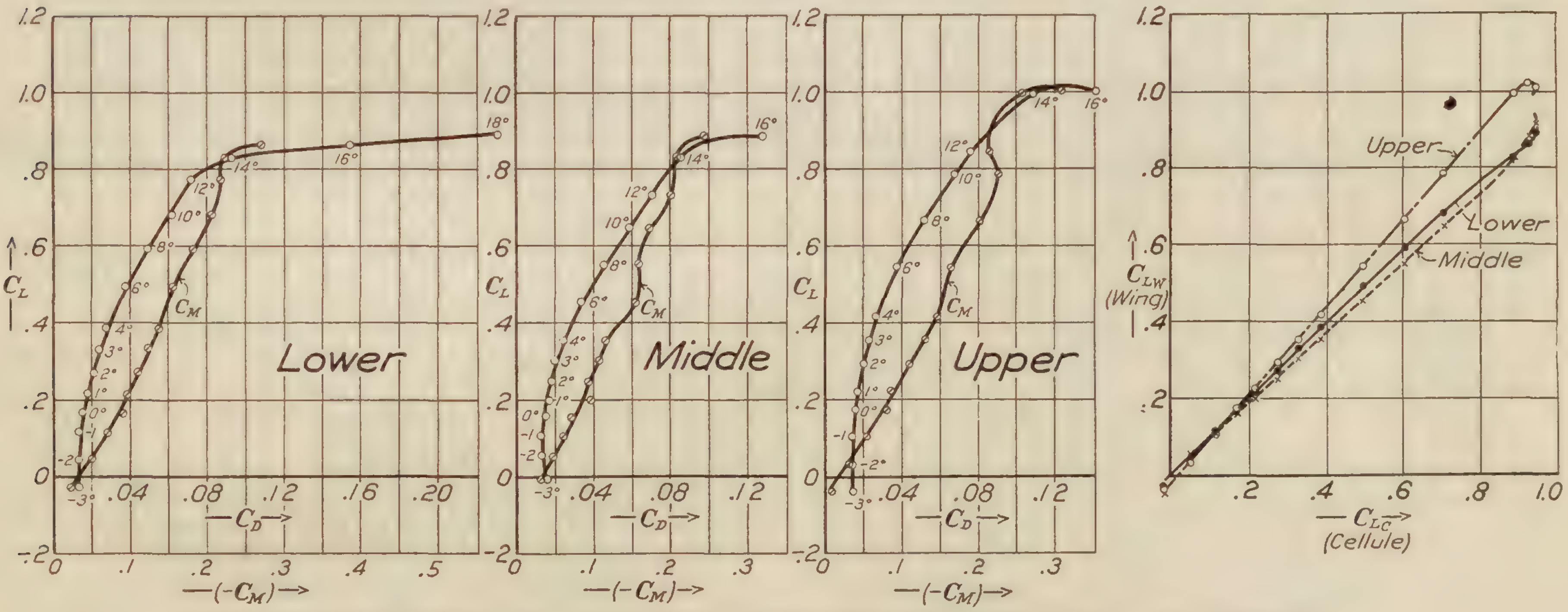


FIG. 28.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 triplane. $G/c=1.0$; Stagger 0°

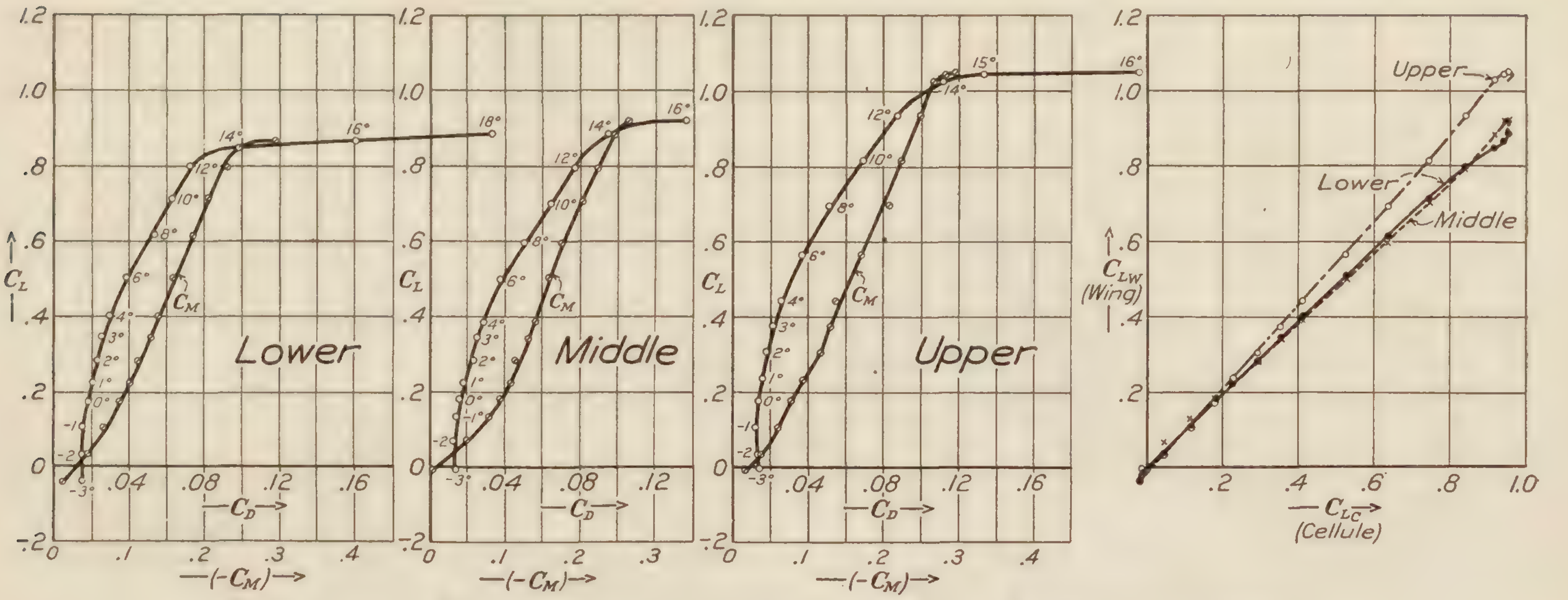


FIG. 29.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 triplane. $G/c=1.2$; Stagger 0°

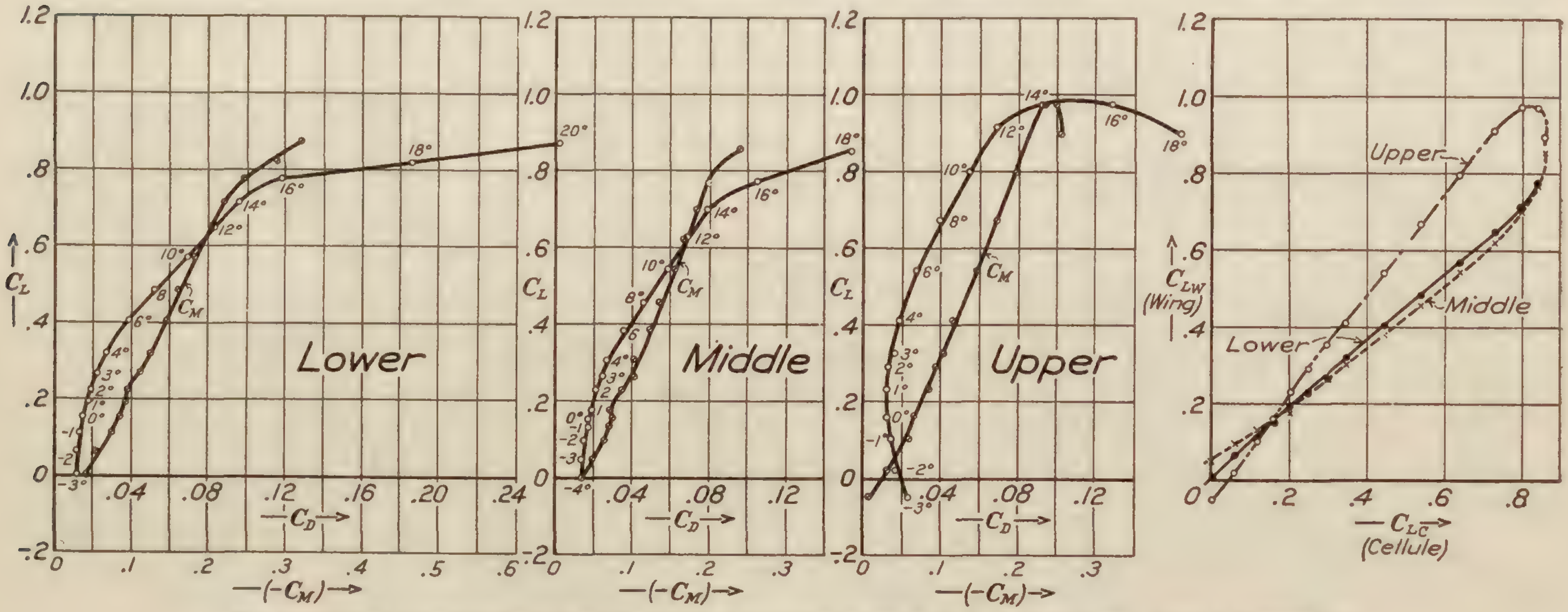


FIG. 30.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 triplane. $G/c=0.6$; Stagger +15°

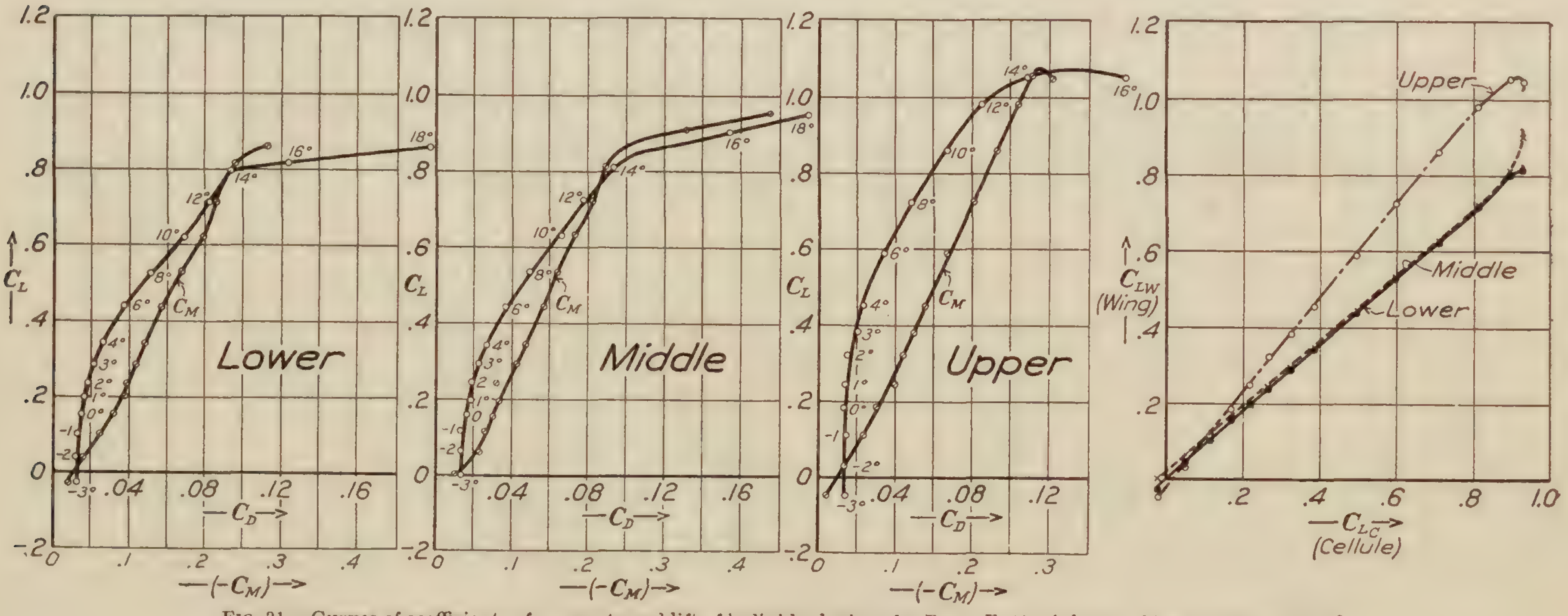


FIG. 31.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 triplane. $G/c=0.9$; Stagger +15°

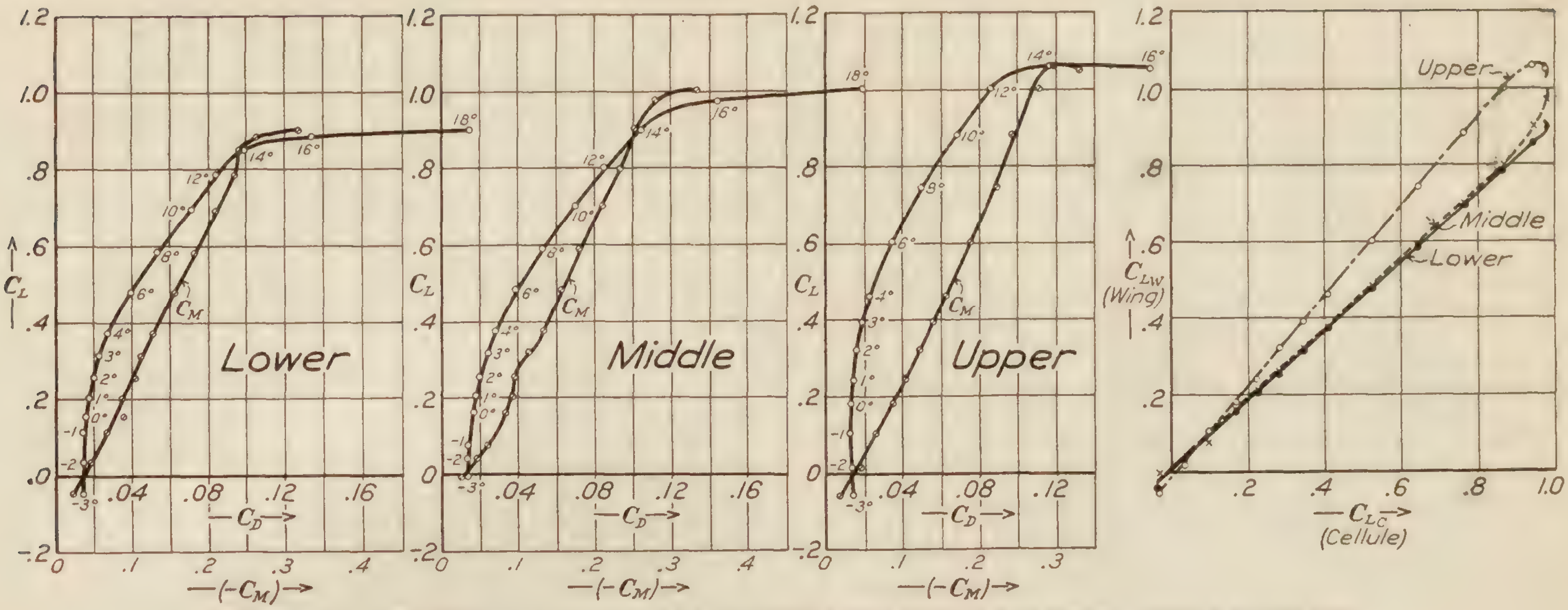


FIG. 32.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 triplane. $G/c=1.2$; Stagger +15°

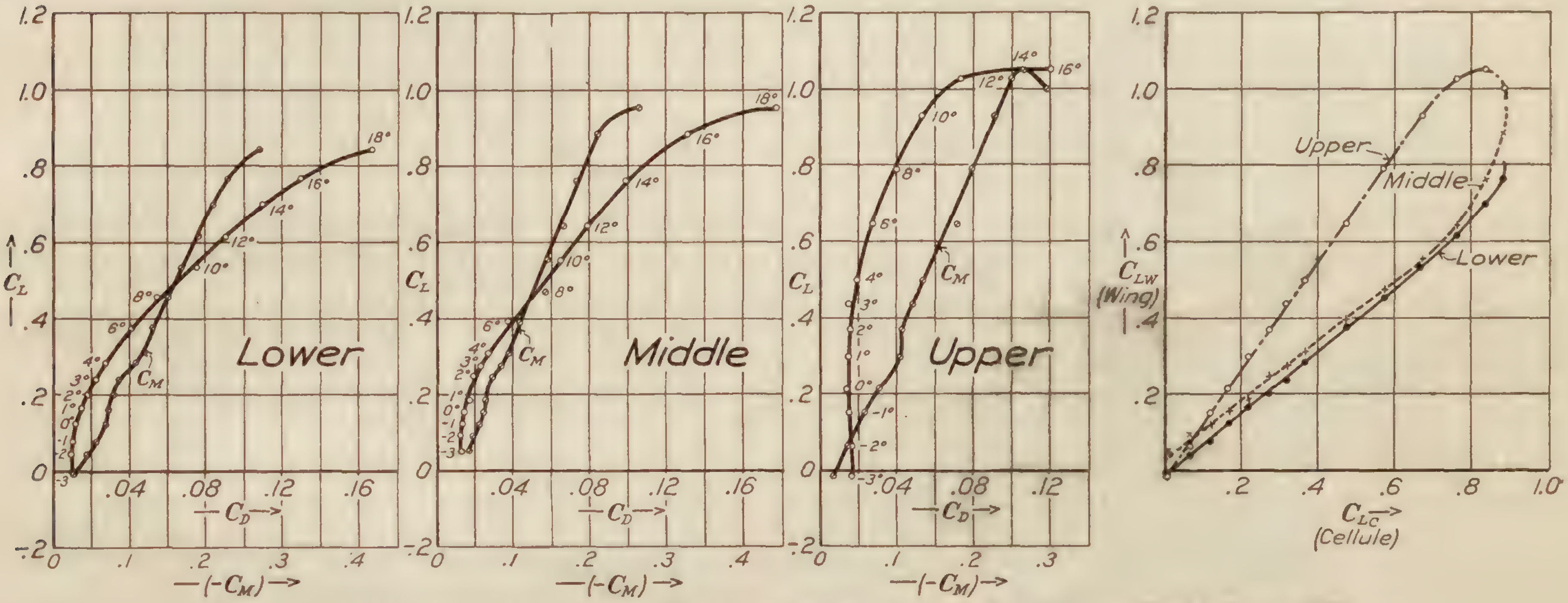


FIG. 33.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 triplane. $G/c=0.6$; Stagger +30°

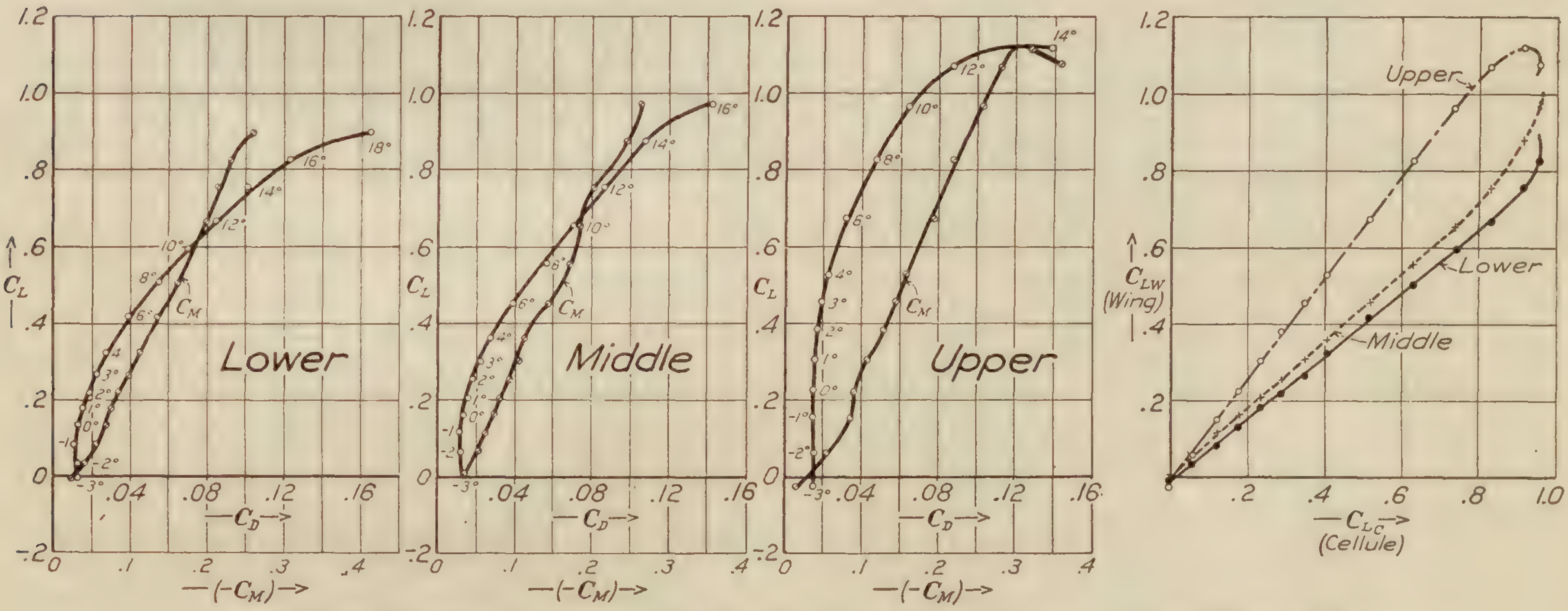


FIG. 34.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 triplane. $G/c=0.9$; Stagger +30°

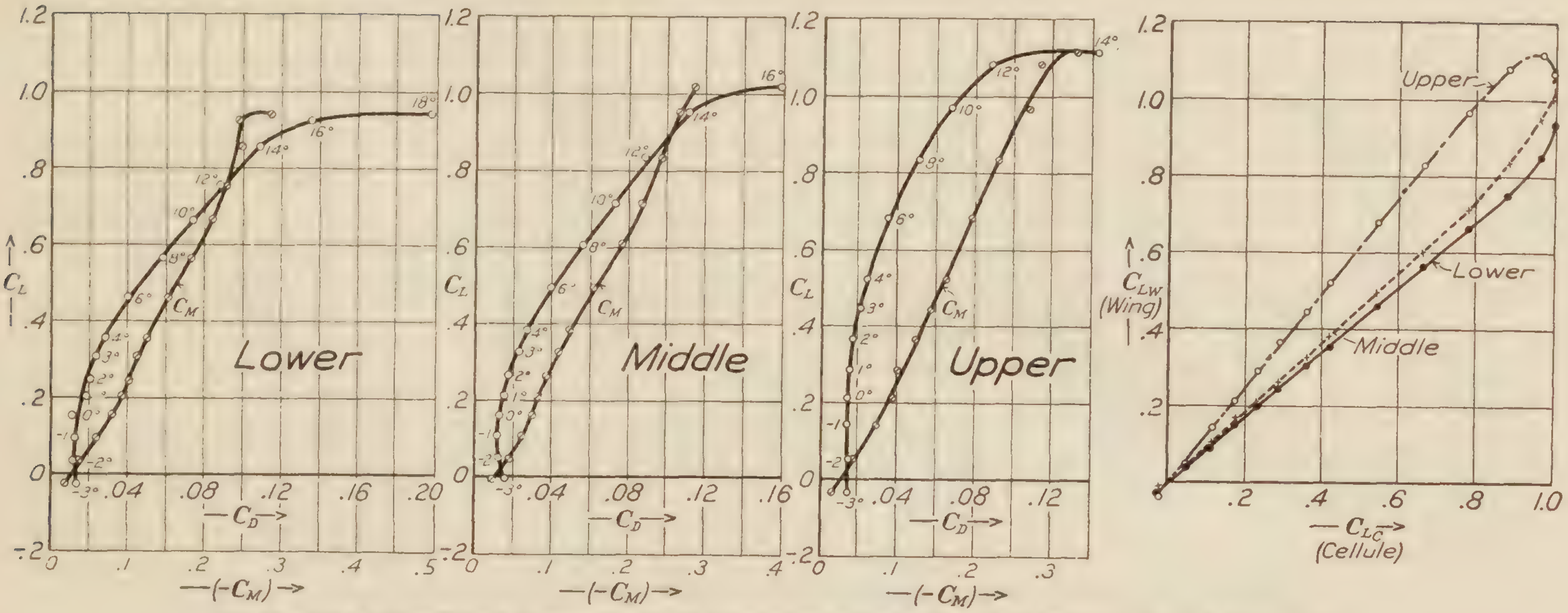


FIG. 35.—Curves of coefficients of moments and lift of individual wings for R. A. F. 15 triplane. $G/c=1.2$; Stagger +30°

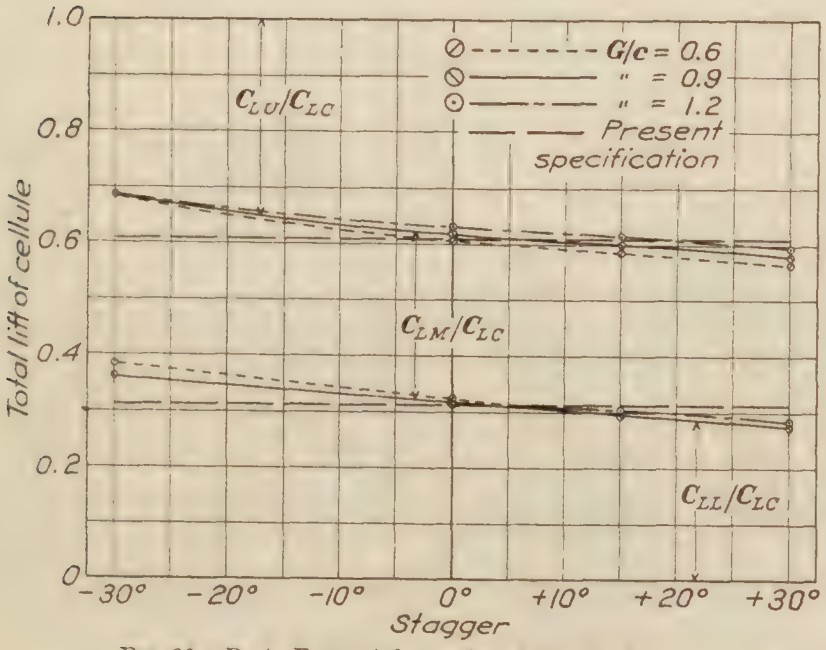


FIG. 36.—R A. F. 15 triplane relative lift at 0.9 maximum lift

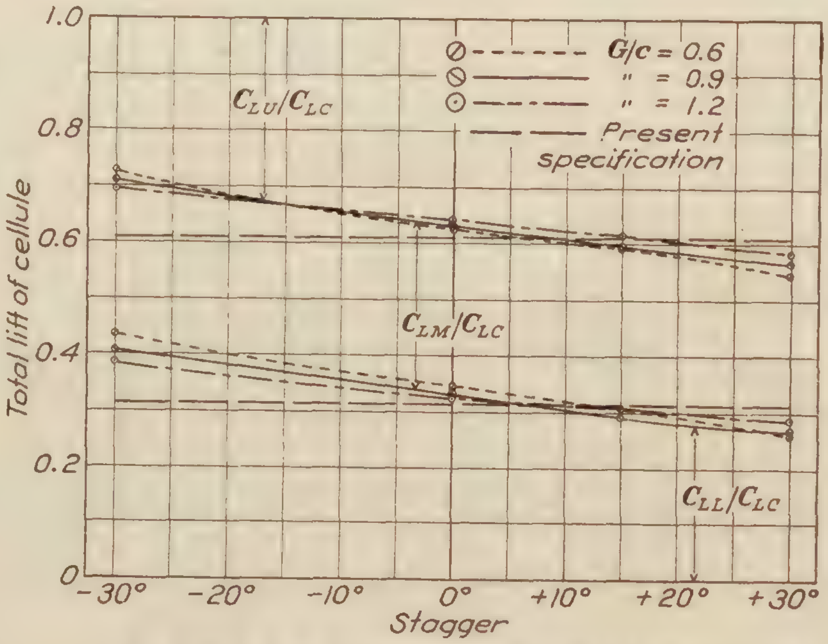


FIG. 37.—R. A. F. 15 triplane relative lift at 0.5 maximum lift

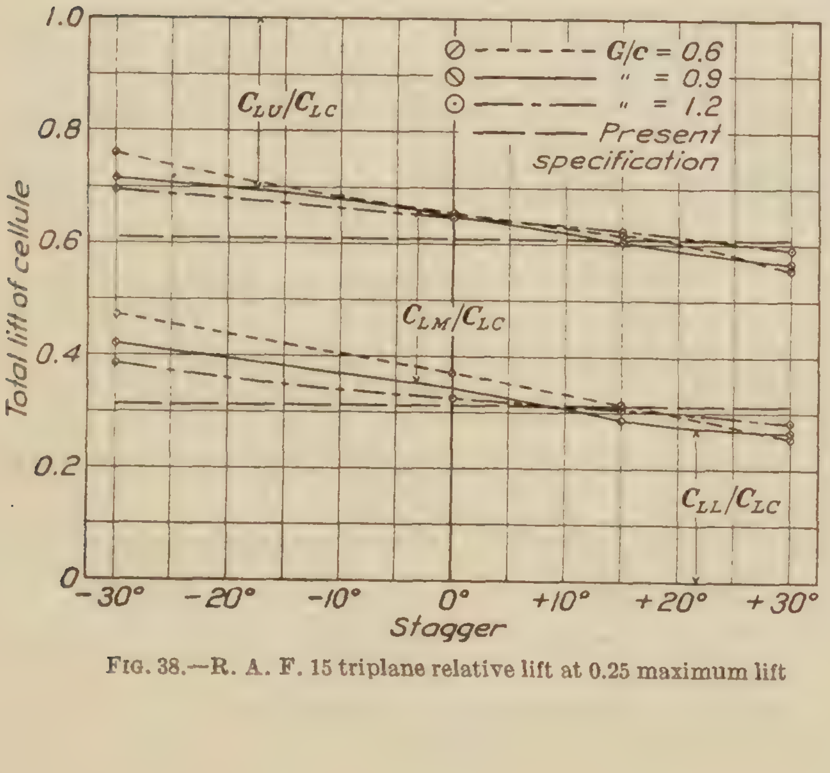


FIG. 38.—R. A. F. 15 triplane relative lift at 0.25 maximum lift

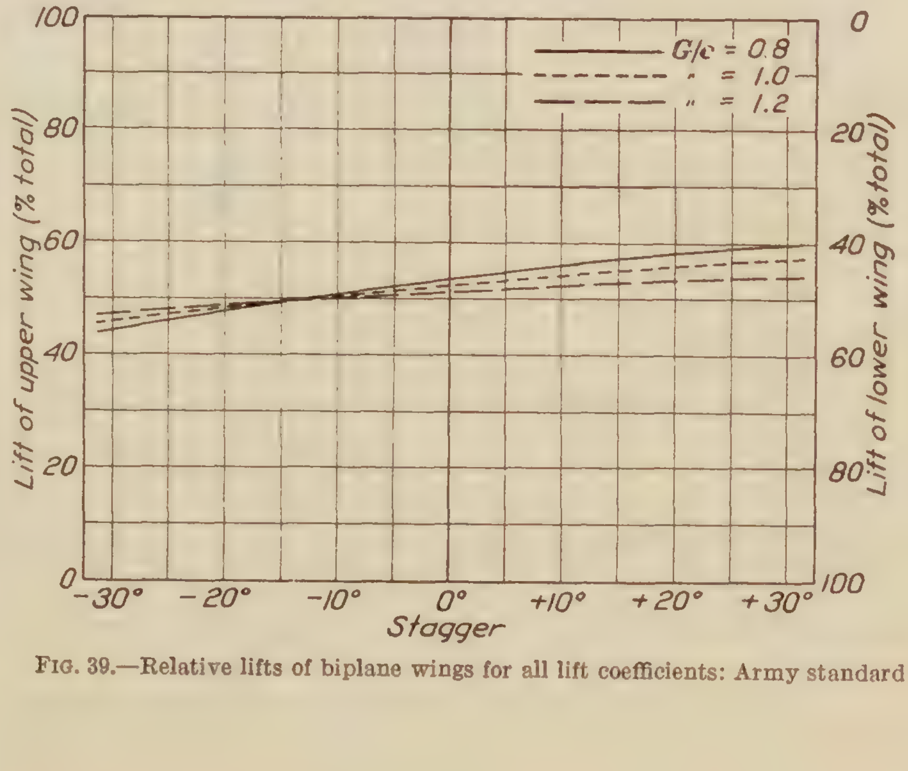


FIG. 39.—Relative lifts of biplane wings for all lift coefficients: Army standard.

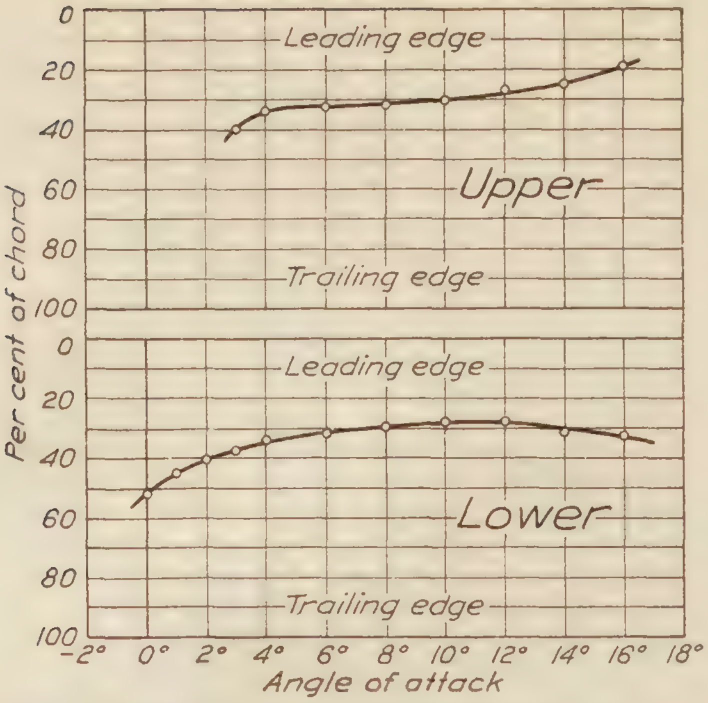


FIG. 40.—Centers of pressure in per cent of chord for R. A. F. 15 biplane. $G/c=0.6$; Stagger −30°

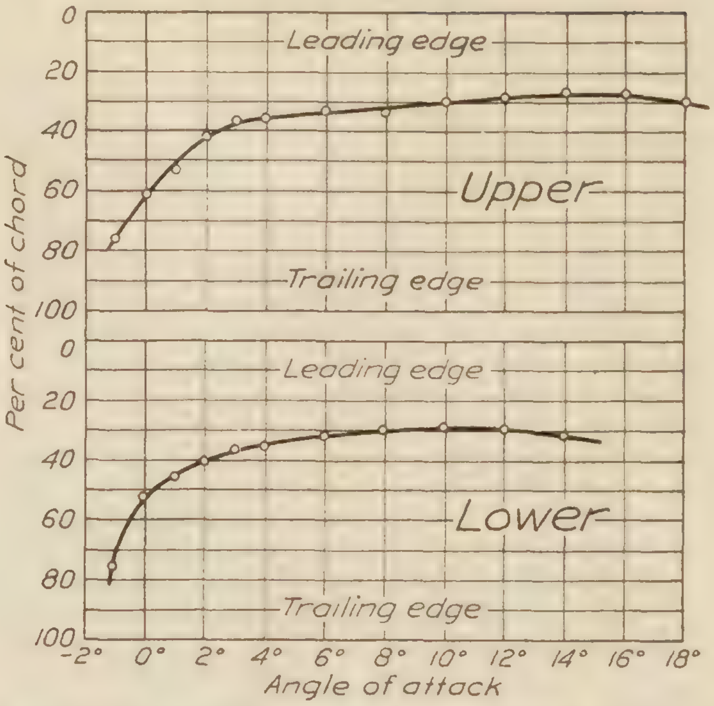


FIG. 41.—Centers of pressure in per cent of chord for R. A. F. 15 biplane. $G/c=0.9$; Stagger −30°

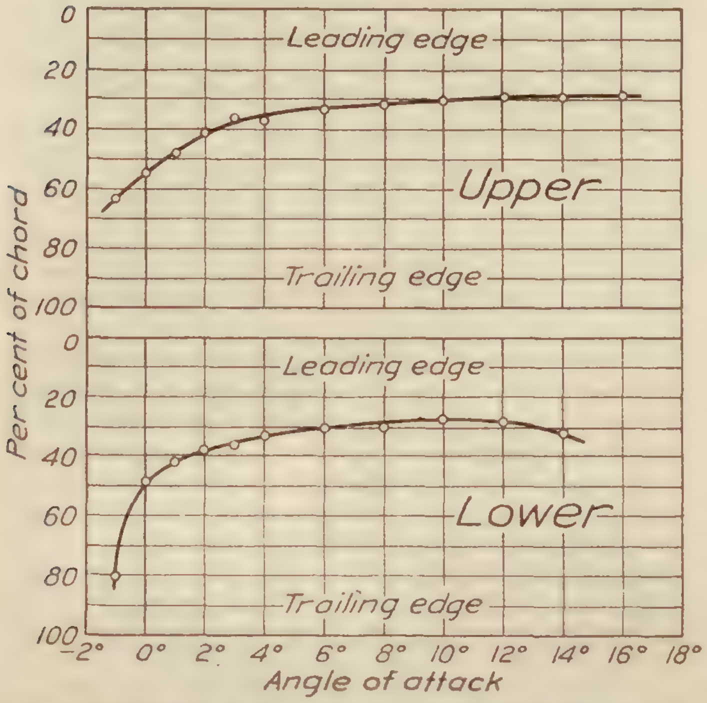


FIG. 42.—Centers of pressure in per cent of chord for R. A. F. 15 biplane. $G/c=1.2$; Stagger −30°

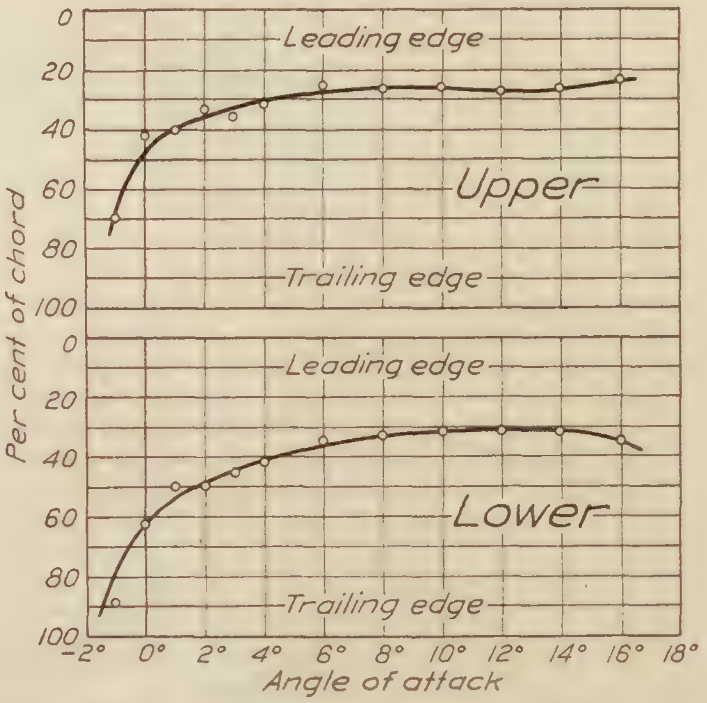


FIG. 43.—Centers of pressure in per cent of chord for R. A. F. 15 biplane. $G/c=0.6$; Stagger 0°

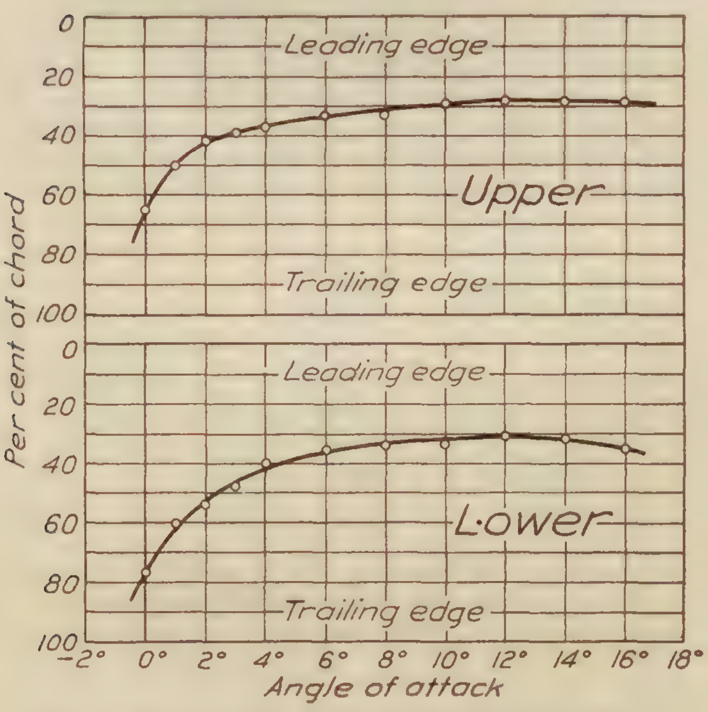


FIG. 44.—Centers of pressure in per cent of chord for R. A. F. 15 biplane. $G/c=0.8$; Stagger 0°

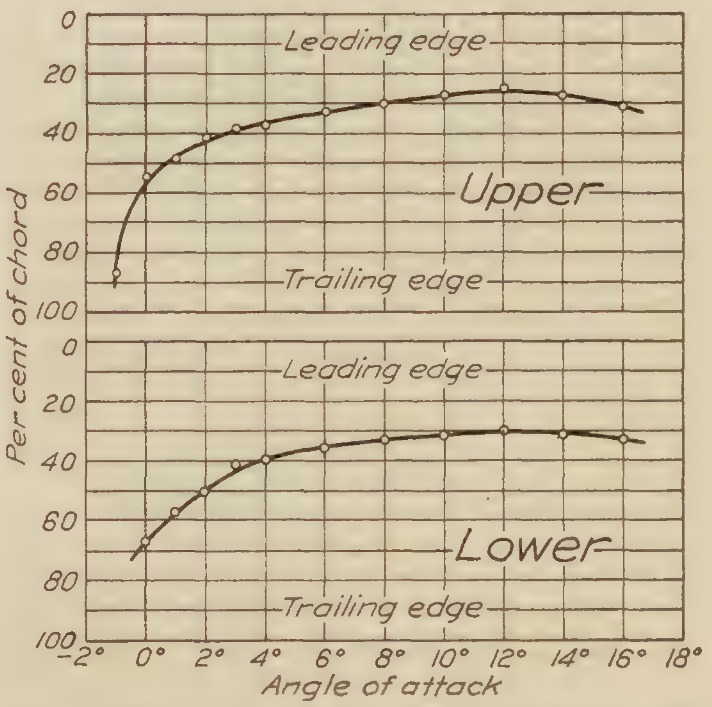


FIG. 45.—Centers of pressure in per cent of chord for R. A. F. 15 biplane. $G/c=1.0$; Stagger 0°

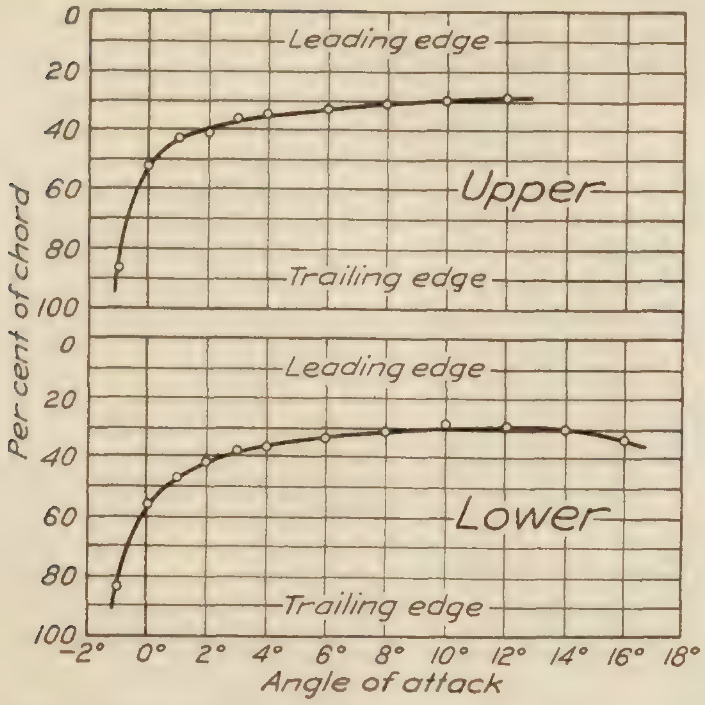


FIG. 46.—Centers of pressure in per cent of chord for R. A. F. 15 biplane. $G/c=1.2$; Stagger 0°

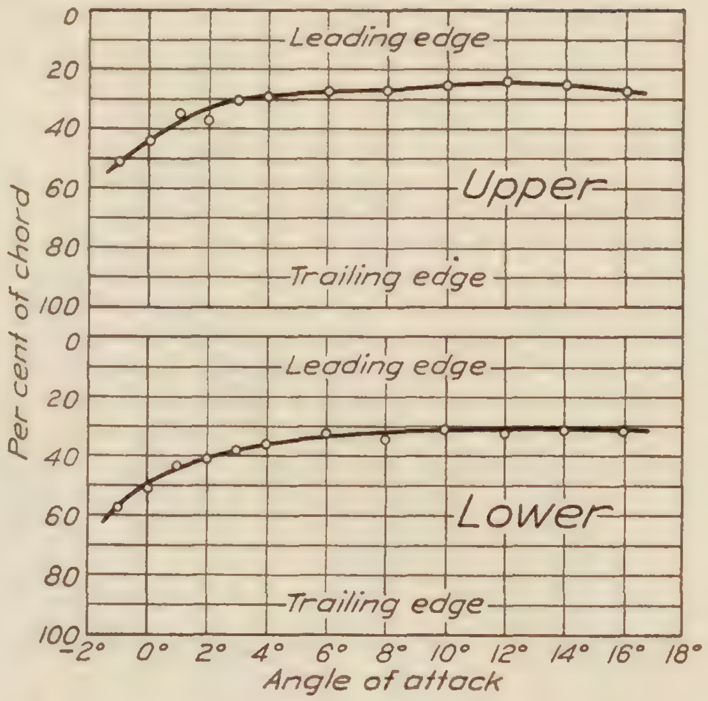


FIG. 47.—Centers of pressure in per cent of chord for R. A. F. 15 biplane. $G/c=0.6$; Stagger +15°

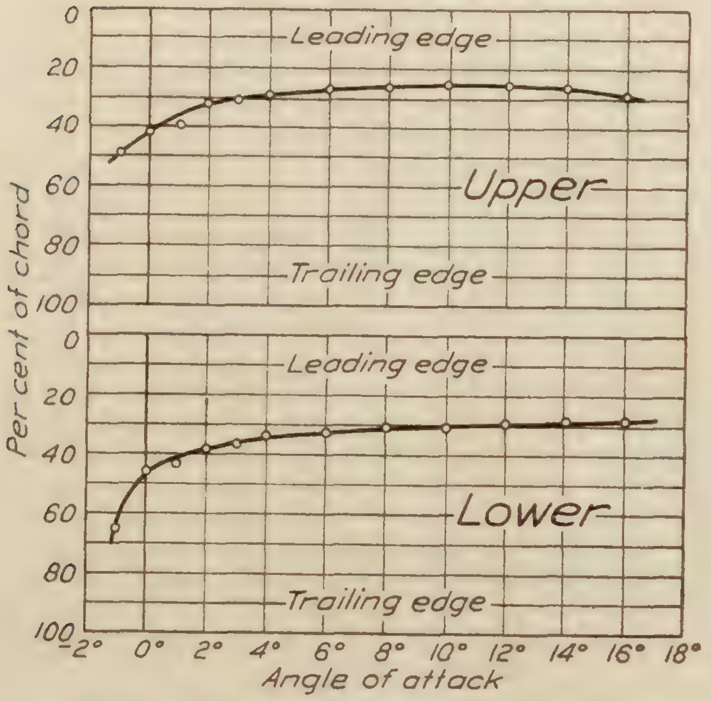


FIG. 48.—Centers of pressure in per cent of chord for R. A. F. 15 biplane. $G/c=0.9$; Stagger +15°

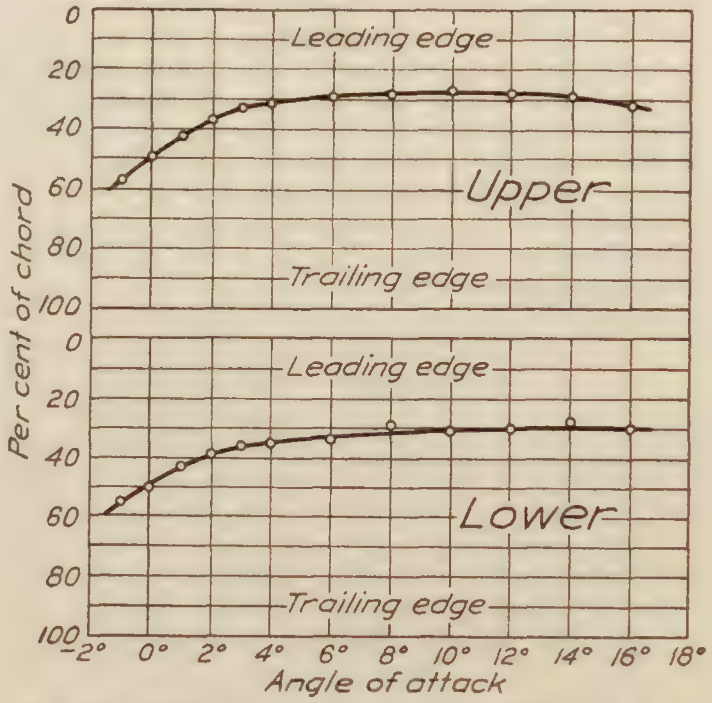


FIG. 49.—Centers of pressure in per cent of chord for R A. F. 15 biplane. $G/c=1.2$; Stagger +15°

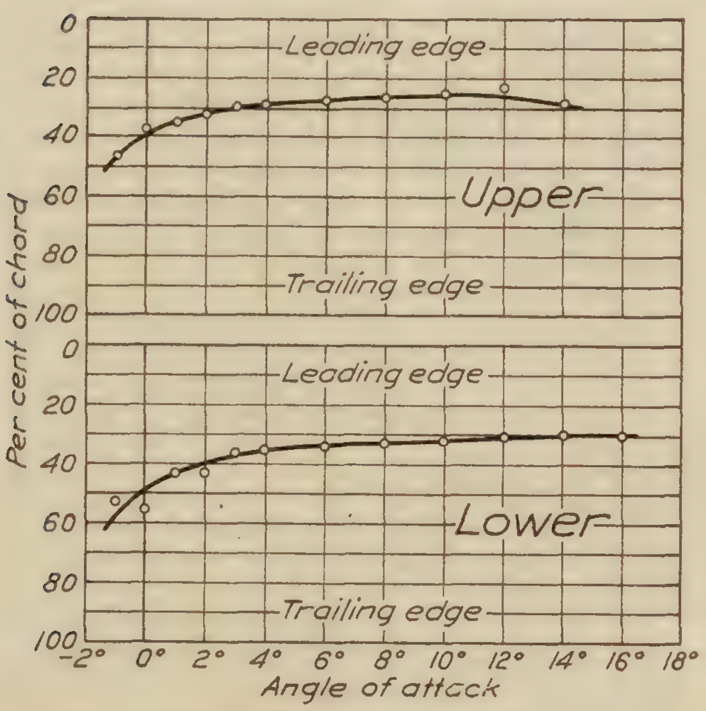


FIG. 50.—Centers of pressure in per cent of chord for R. A. F. 15 biplane. $G/c=0.6$; Stagger +30°

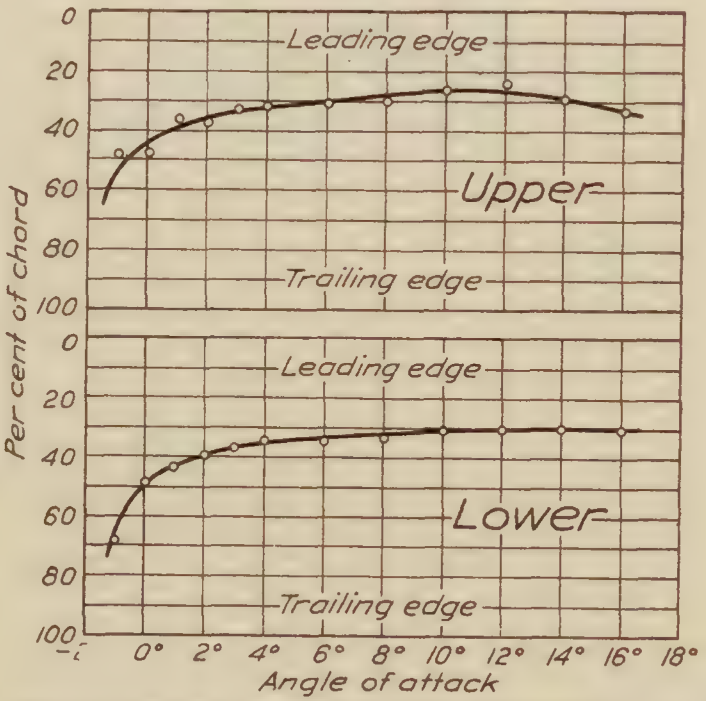


FIG. 51.—Centers of pressure in per cent of chord for R. A. F. 15 biplane. $G/c=0.9$; Stagger +30°

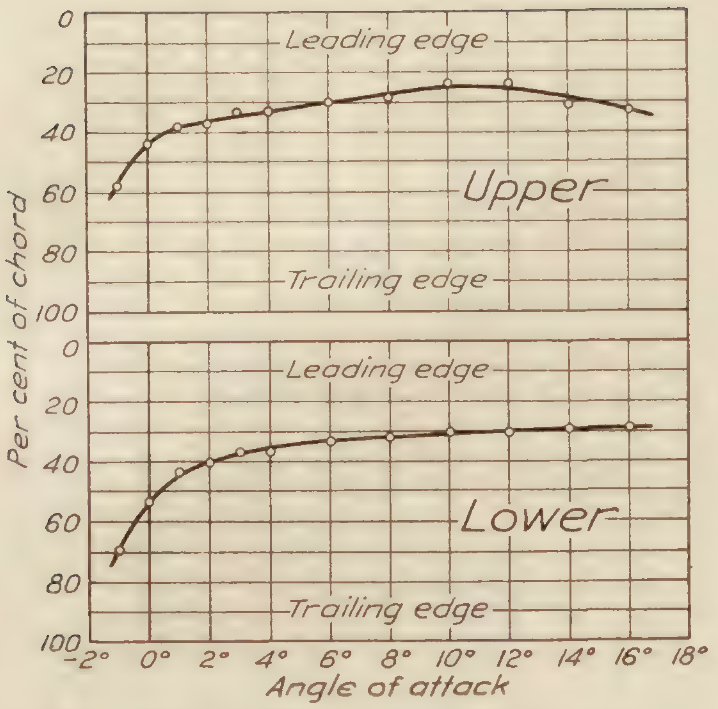


FIG. 52.—Centers of pressure in per cent of chord for R. A. F.; 15 biplane. $G/c=1.2$ Stagger +30°

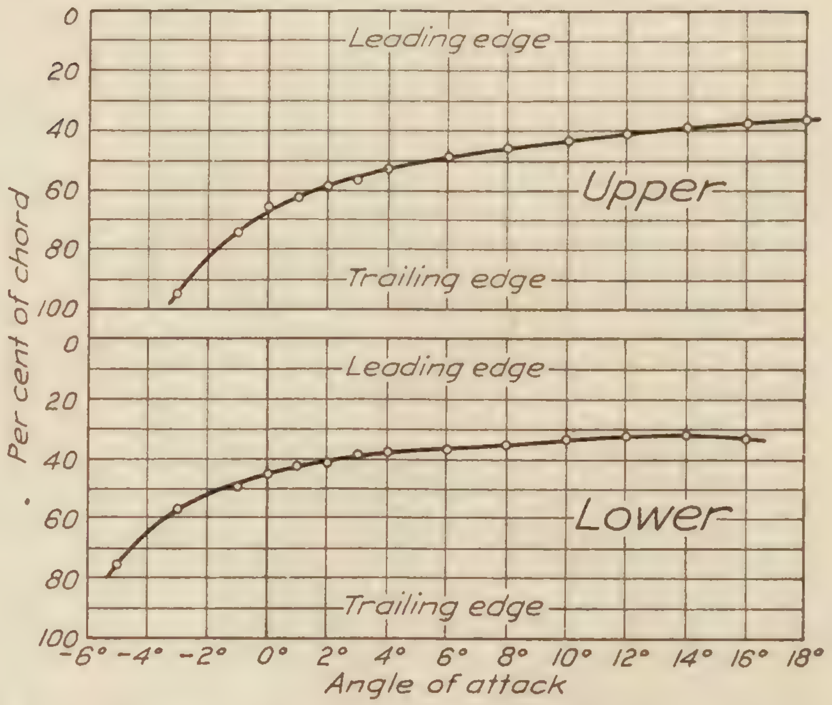


FIG. 53.—Centers of pressure in per cent of chord for U. S. A. T. S. 5 biplane. $G/c=0.9$; Stagger −30°

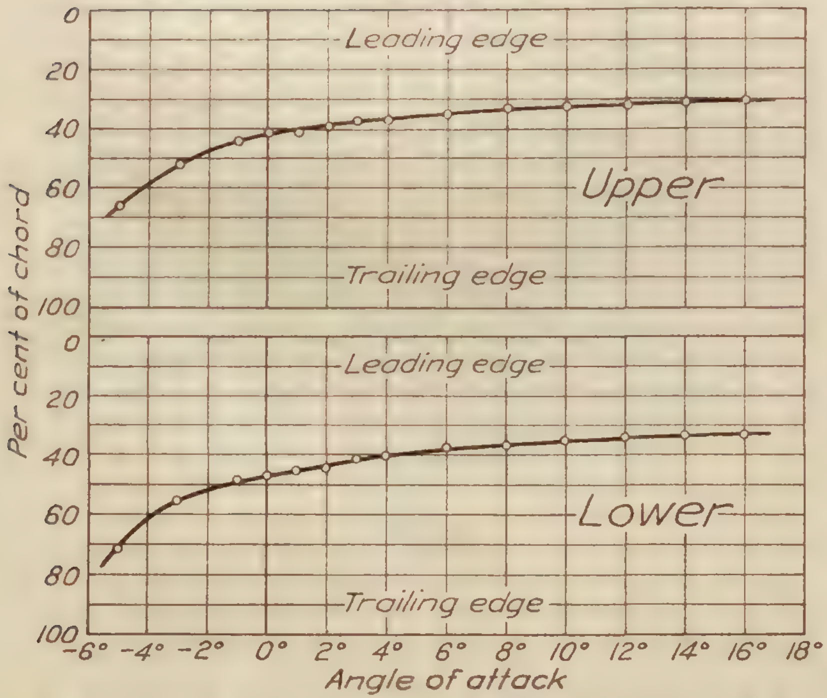


FIG. 54.—Centers of pressure in per cent of chord for U. S. A. T. S. 5 biplane. $G/c=0.9$; Stagger 0°

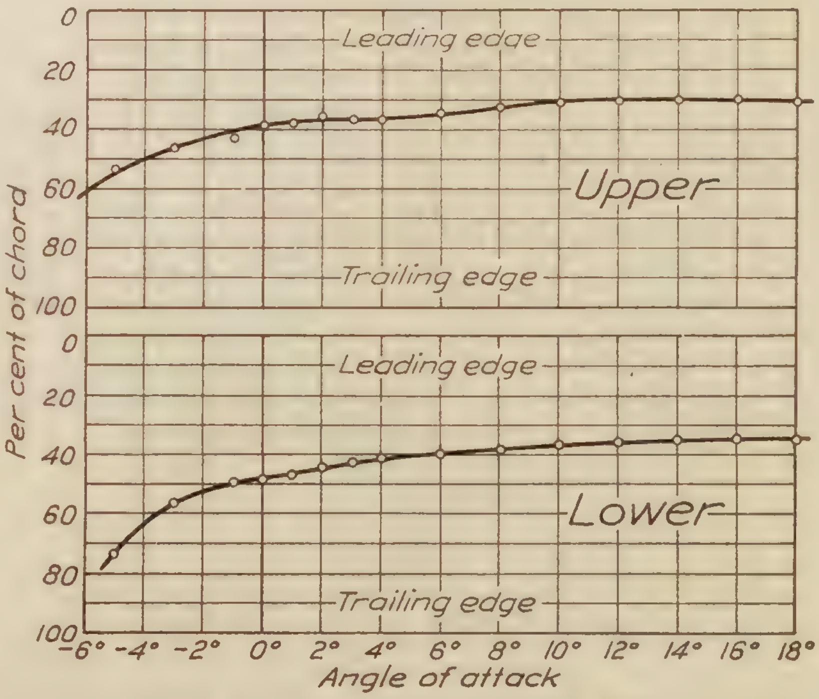


FIG. 55.—Centers of pressure in per cent of chord for U. S. A. T. S. 5 biplane. $G/c=0.9$; Stagger +30°

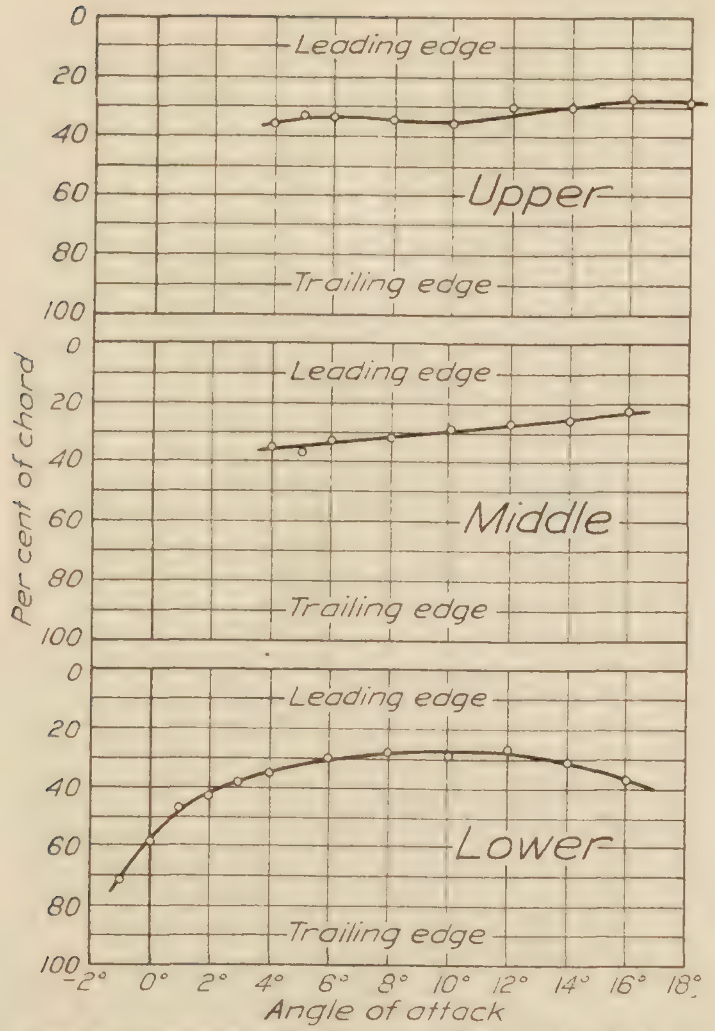


FIG. 56.—Centers of pressure in per cent of chord for R. A. F. 15 triplane. $G/c=0.6$; Stagger −30°

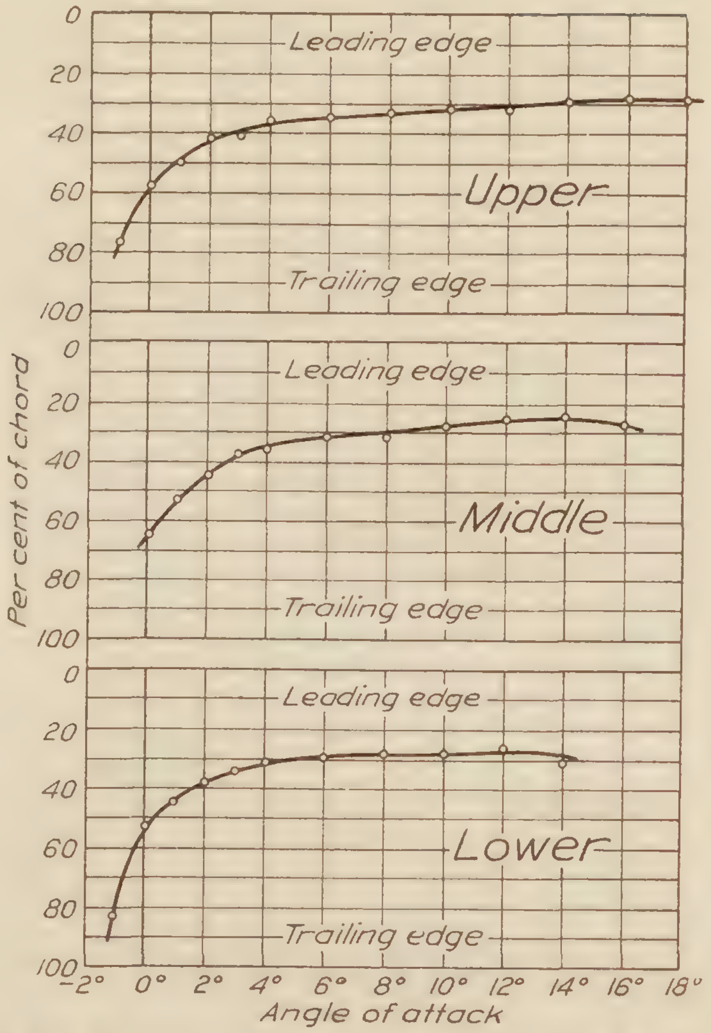


FIG. 57.—Centers of pressure in per cent of chord for R. A. F. 15 triplane. $G/c=0.9$; Stagger −30°

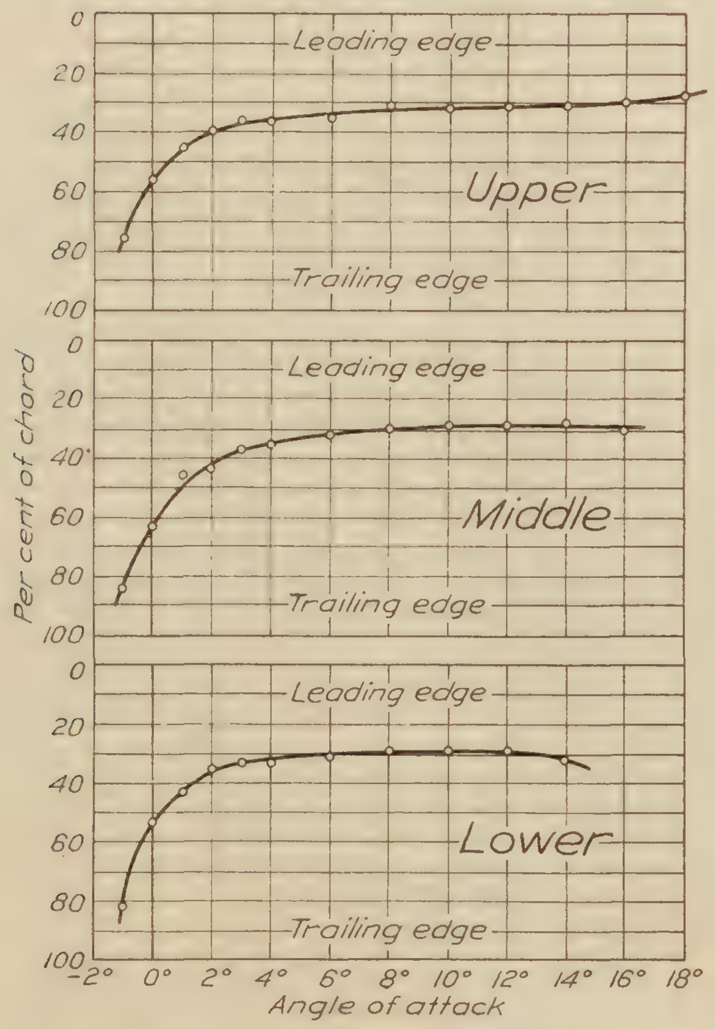


FIG. 58.—Centers of pressure in per cent of chord for R. A. F. 15 triplane. $G/c=1.2$; Stagger −30°

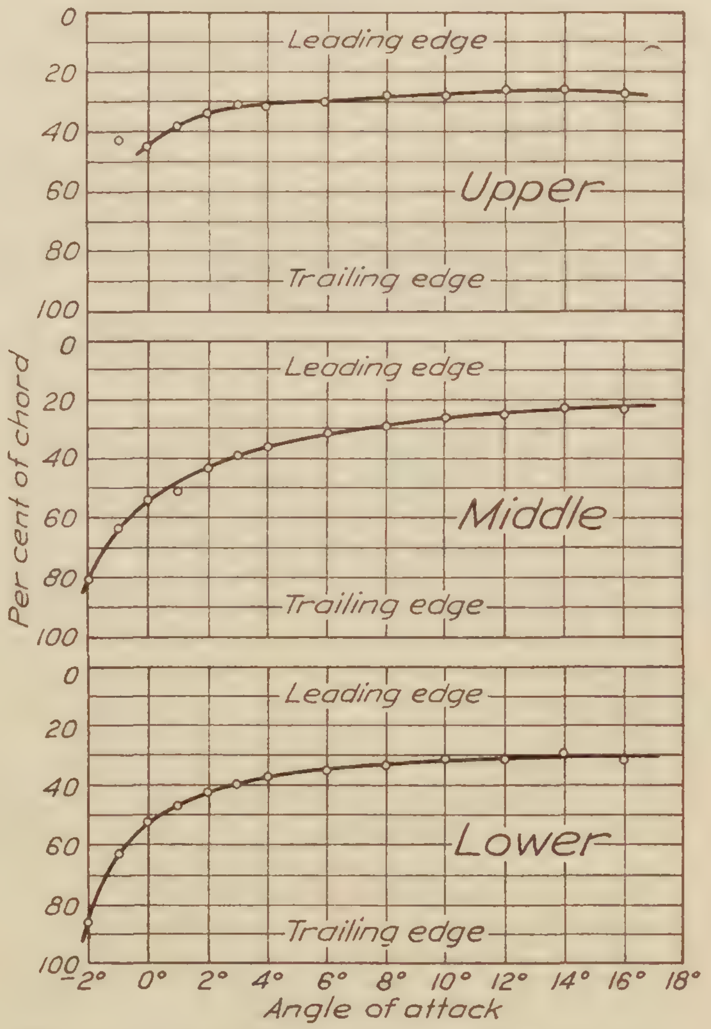


FIG. 59.—Centers of pressure in per cent of chord for R. A. F. 15 triplane. $G/c=0.6$; Stagger 0°

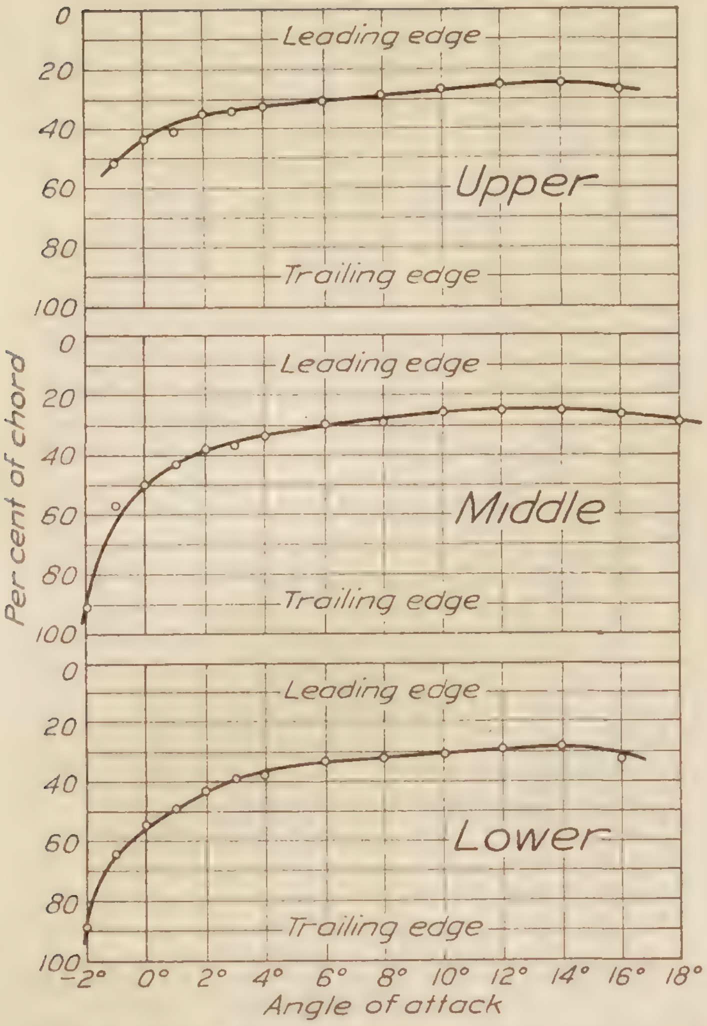


FIG. 60.—Centers of pressure in per cent of chord for R. A. F. 15 triplane. $G/c=0.8$; Stagger 0°

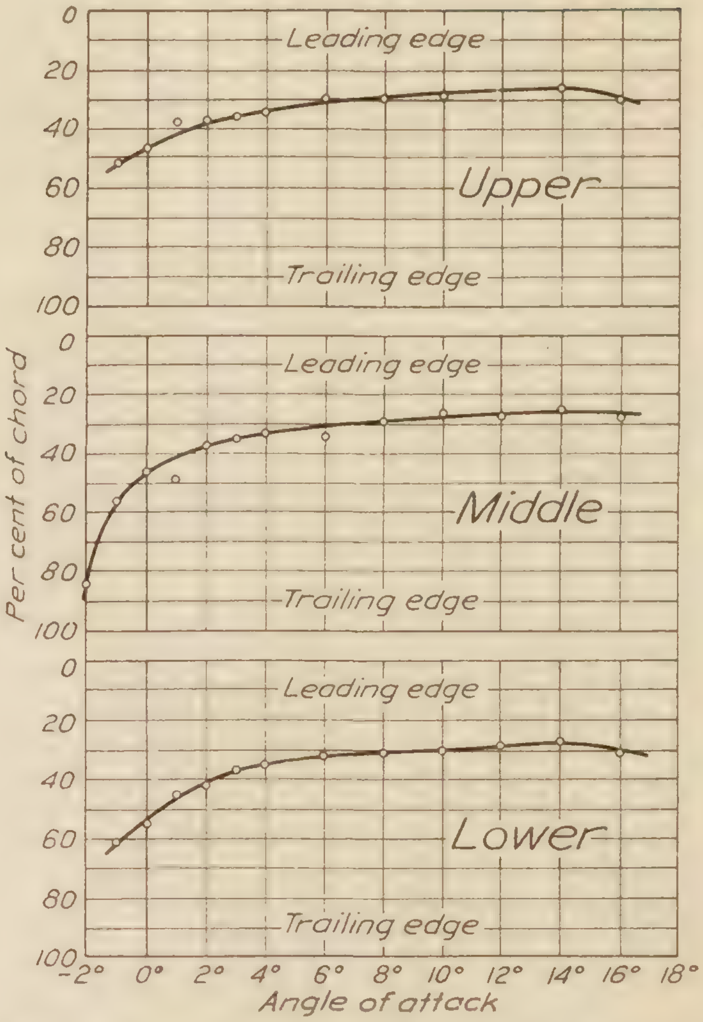


FIG. 61.—Centers of pressure in per cent of chord for R. A. F. 15 triplane. $G/c=1.0$; Stagger 0°

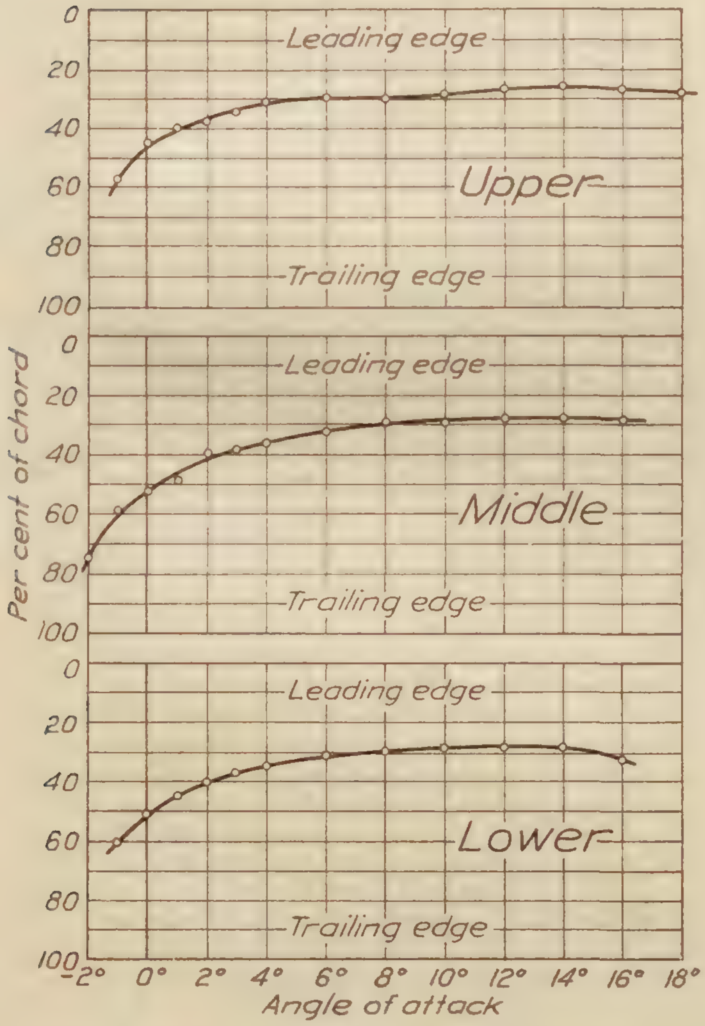


FIG. 62.—Centers of pressure in per cent of chord for R. A. F. 15 triplane. $G/c=1.2$; Stagger 0°

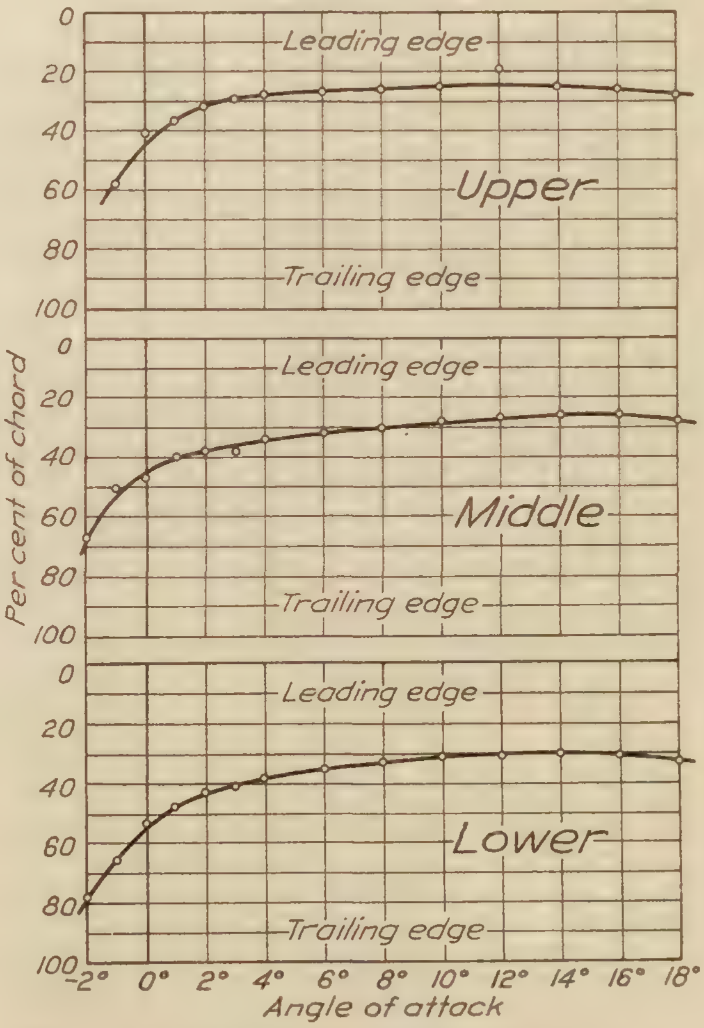


FIG. 63.—Centers of pressure in per cent of chord for R. A. F. 15 triplane. $G/c=0.6$; Stagger +15°

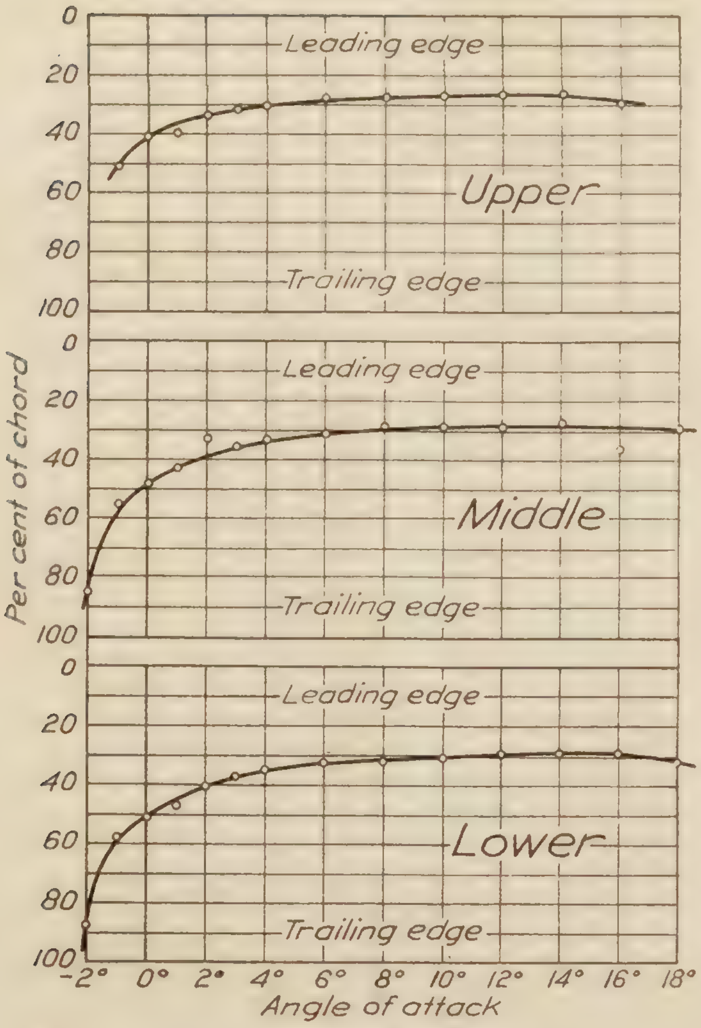


FIG. 64.—Centers of pressure in per cent of chord for R. A. F. 15 triplane. $G/c=0.9$; Stagger +15°

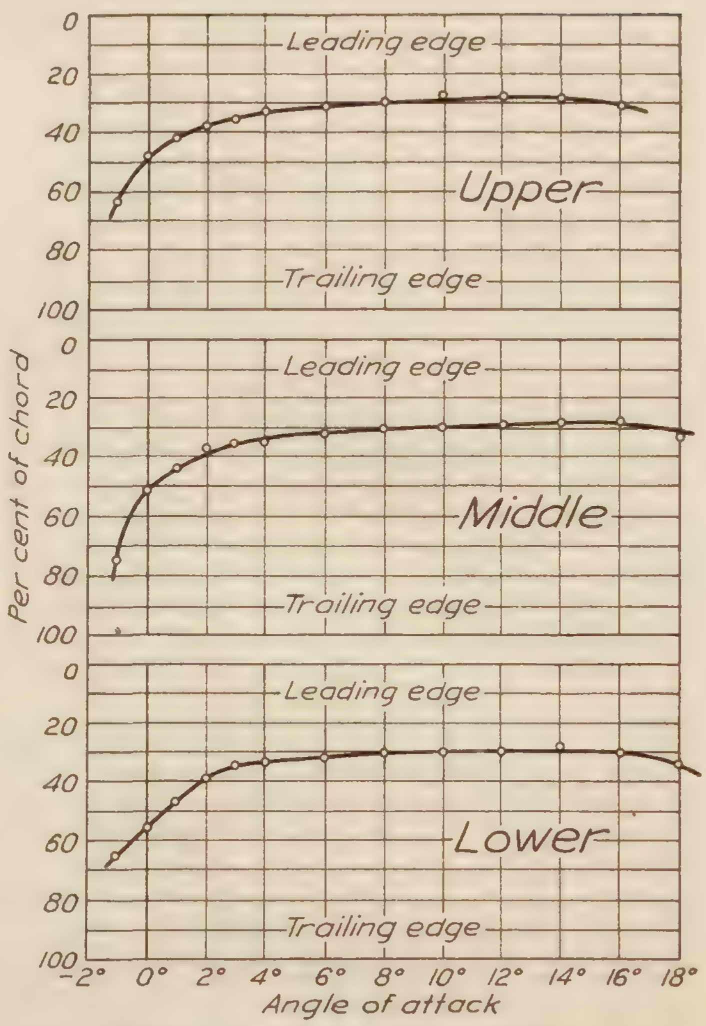


FIG. 65.—Centers of pressure in per cent of chord for R. A. F. 15 triplane. $G/c=1.2$; Stagger +15°

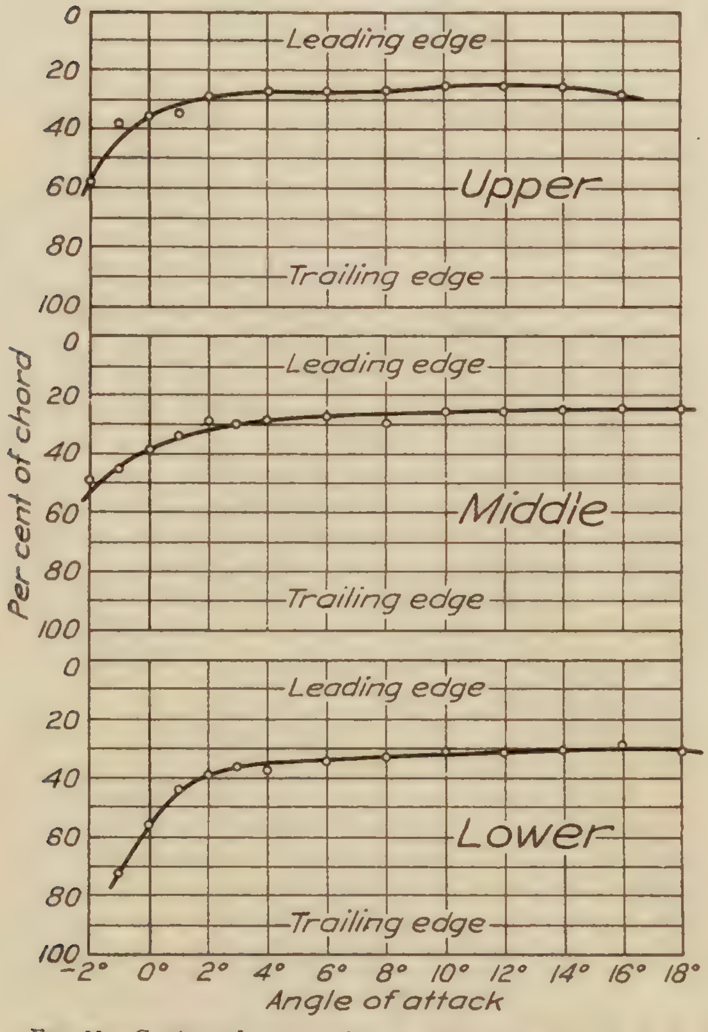


FIG. 66.—Centers of pressure in per cent of chord for R. A. F 15 triplane. $G/c=0.6$; Stagger +30°

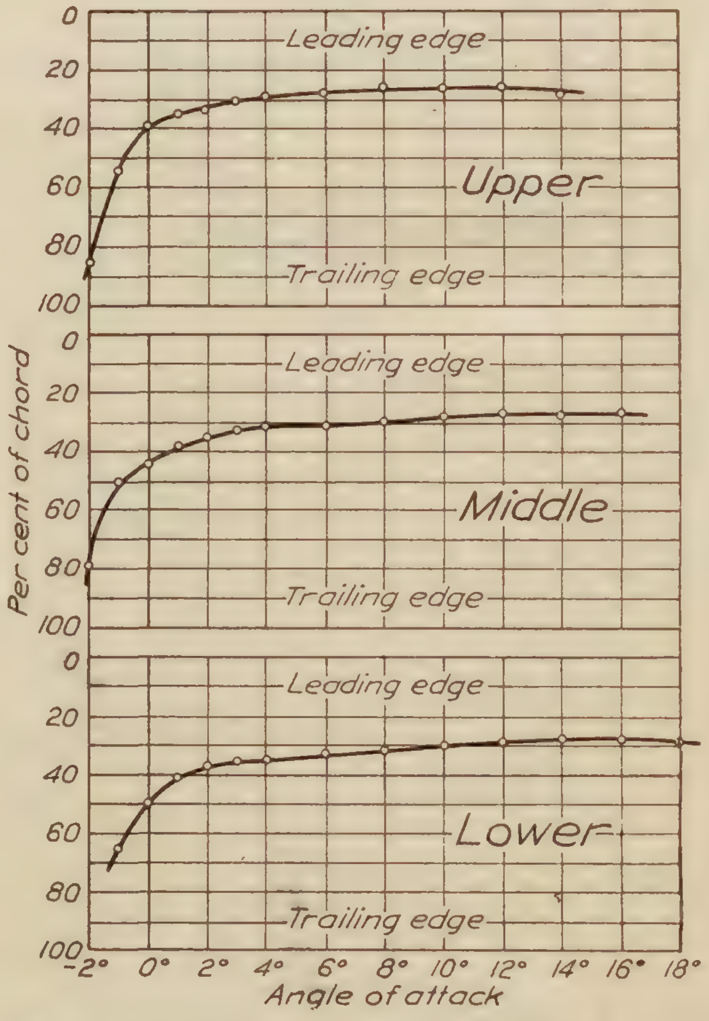


FIG. 67.—Centers of pressure in per cent of chord for R. A. F. 15 triplane. $G/c=0.9$;Stagger +30°

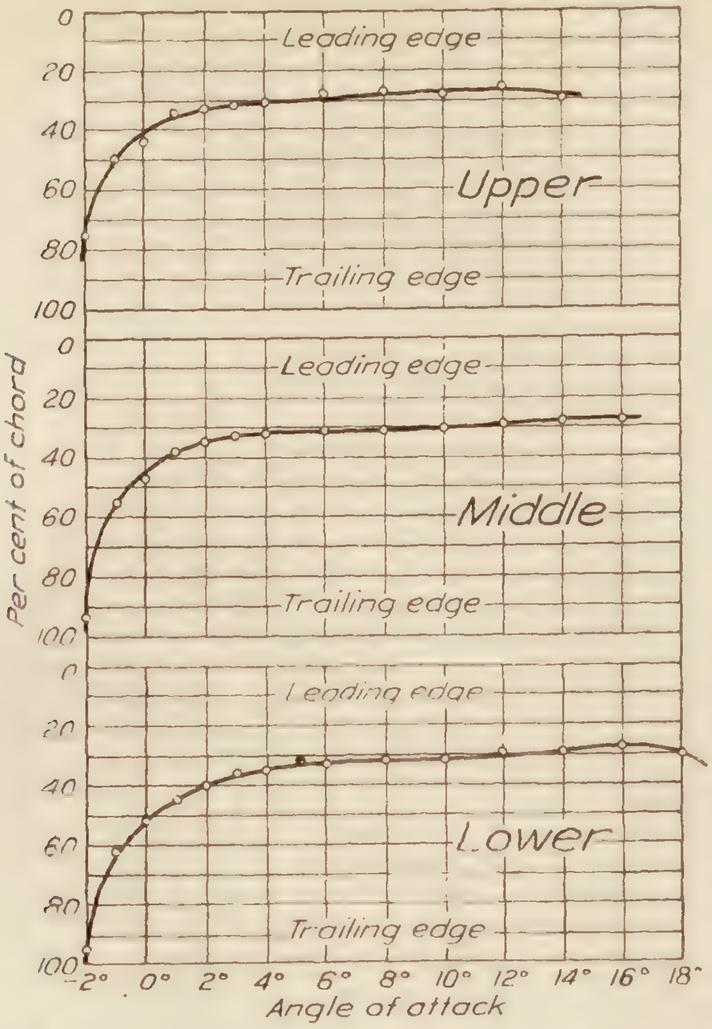


FIG. 68.—Centers of pressure in per cent of chord for R. A. F. 15 triplane. $G/c=1.2$; Stagger +30°

SMITHSONIAN INSTITUTION LIBRARIES

SMITHSONIAN INSTITUTION LIBRARIES

SMITHSONIAN LIBRARIES
3 9088 01800 8151